Engineers Australia
Engineering Heritage Victoria

Nomination

Engineering Heritage Australia, Heritage Recognition Program

for

MONIER BRIDGES in BENDIGO

Bendigo, 130km north-west of Melbourne, Victoria

Early examples of the Monier Concrete Arch Construction Method

May 2014

Front Cover Photograph Caption

King's Bridge (Weeroona Avenue) [Note that this is the second bridge on this site] in 2014 taken from the downstream side on the southern bank of Bendigo Creek looking towards the southwest.

The underside of the arch reveals two problems, which 113 years of service have illuminated; the dark mark is water draining from the spandrel fill. Water in this fill is thought to have contributed to expansion of the fill, which has caused outward swelling of the spandrel walls. To resolve this issue holes have been bored into the underside of the arch to drain the fluid build-up. The other problem is spalling of concrete from the underside of the arch. The causes of deterioration of reinforced concrete were unknown at the time of construction of the Monash & Anderson Monier bridges. By modern standards the cover to the reinforcement was inadequate as was the compaction of the concrete. Using present-day concrete technology the spalled concrete can be repaired. Patches and repairs have been made to the exposed reo in the bridge.

Image: Owen Peake, Jan 2014

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1 Introduction

Engineering Heritage Victoria (EHV) has a program within its Heritage Recognition initiative to recognise structures built by General Sir John Monash, the firm Monash and Anderson (M&A) and various companies with which Monash was associated as a contribution towards the celebration of the centenary of the ANZAC Campaign in 2015.

Originally, a group of eight bridges were built by Monash and Anderson in Bendigo. They are all Monier arch bridges with a single arch, except for the second bridge at King's Bridge (Weeroona Avenue) which has two arches. Of the 8 Monier bridges built in Bendigo, six remain, and are located at:

- King's Bridge (Weeroona Avenue) [Note that this is the second bridge on this site]
- Abbott Street Bridge [on Back Creek / Spring Creek]
- High Street Bridge
- Thistle Street Bridge
- Booth Street Bridge
- Wade Street Bridge

All the bridges are situated on Bendigo Creek in Central Bendigo except Abbott Street Bridge which is nearby on a tributary known as Back Creek or Spring Creek.

The Monier system of reinforced concrete had been brought to Australia late in the 19th century by the engineering and contracting firm Carter, Gummow & Co who had acquired the New South Wales and Victorian patent rights. Monash & Anderson subsequently gained the rights for Victoria and South Australia which enabled them to design and construct their first bridge at Fyansford in Victoria in 1899/1900.

The technique was novel at the time and Monash & Anderson had to work hard to convince potential bridge owners that the technique was reliable and cost effective.

The 8 bridges in Bendigo represent the centre group of the 18 bridges built by Monash & Anderson under the Monier patents. The first group consisted of the two multi-span bridges at Fyansford and Wheelers Bridge in 1900. The eight Bendigo Bridges were built close together between 1901 and 1902. A further 7 Monier arch bridges were built at various other localities by Monash & Anderson during the period 1901 to 1913.

By about 1910 it had become apparent that more efficient reinforced concrete bridges using reinforced "T" shaped concrete beams represented the future for reinforced concrete bridges. This style remains in common use today, although "T" beams may be pre-stressed or post-stressed in modern practice.

The Monier arch bridges are therefore significant in that they represent an important 'stepping stone' in the development of reinforced concrete bridges.

2 Heritage Award Nomination Letter

The Administrator
Engineering Heritage Australia
Engineers Australia
Engineering House
11 National Circuit
BARTON ACT 2600

Name of works:

- King's Bridge (Weeroona Avenue)
- Abbott Street Bridge
- High Street Bridge
- Thistle Street Bridge
- Booth Street Bridge
- Wade Street Bridge

The above-mentioned six Monier Bridges are nominated for an award under the Engineering Heritage Recognition Program.

Locations, including address and map grid reference of the bridges:

King's Bridge:
Weeroona Avenue, Bendigo, Victoria.
Grid reference: -36º74'36.4" S, 144º29'16.5" E
Altitude = 213.926 m / 701.856 feet

Abbott Street Bridge:
Abbott Street, Bendigo, Victoria.
Grid reference: -36º75'83.47" S, 144º28'99.17" E
Altitude = 219.773 m / 721.039 feet

High Street Bridge:
High Street, Bendigo, Victoria.
Grid reference: -36º76'96.28" S, 144º26'38.67" E
Altitude = 229.024 m / 751.390 feet

Thistle Street Bridge:
Thistle Street, Bendigo, Victoria.
Grid reference: -36º76'83.37" S, 144º26'71.0" E
Altitude = 226.129 m / 741.892 feet

Booth Street Bridge:
Booth Street, Bendigo, Victoria.
Grid reference: -36º76'98.47" S, 144º26'18.39" E
Altitude = 230.790 m / 757.185 feet

Wade Street Bridge:
Wade Street, Bendigo, Victoria.
Grid reference: -36º77'04.2" S, 144º26'08.2" E
Altitude = 231.236 m / 758.649 feet

Owner (name & address): City of Greater Bendigo, 195-229 Lyttleton Terrace, Bendigo VIC 3550.

The owners, City of Greater Bendigo and VicRoads, have been advised of this nomination and a letter of agreement is attached at Appendix 9.

Access to site: Bridges are on public roads in residential areas

Nominating Body: Engineering Heritage Victoria

OWEN PEAKE
Chair, Engineering Heritage Victoria
Date: 25 May 2014

3 Heritage Assessment Basic Data

3.1 Item Name: King’s Bridge [Weeroona Avenue on Bendigo Creek]

First King’S Bridge undergoing testing before the failure.
Image: Melbourne University Archives.

First King’S Bridge after the testing failure.
Image: Melbourne University Archives.

Second King's Bridge. Note that the rebuild has two spans and accommodates 2 lanes of traffic.
Image: Melbourne University Archives.

Second King's Bridge. Bridge has been extended to 4 lanes of traffic, with the addition of a second, connected arch bridge. Jan 2014.
Image: Owen Peake, Jan 2014.

Second King's Bridge. Proposed possible site for Interpretation panel detailing historical significance of King's Bridge and the six remaining Monier Bridges within the Bendigo region.
Image: Owen Peake, Jan 2014.

3.1.1 Other/Former Names: Some sources refer to the bridge as Weeroona Avenue Bridge
3.1.2 Location: Weeroona Avenue
3.1.3 Address: As above
3.1.4 Suburb/Nearest Town: Bendigo
3.1.5 State: Victoria
3.1.6 Local Govt. Area: City of Greater Bendigo
3.1.7 Owner: VicRoads
3.1.8 Current Use: Road Bridge (including pedestrian and bike)
3.1.9 Former Use: Road Bridge (including pedestrian and bike)
3.1.10 Designer: Monash and Anderson, Melbourne
3.1.11 Maker/Builder: Monash and Anderson, Melbourne
3.1.12 Year Started: 1901
3.1.13 Year Completed: 1902
3.1.14 Physical Description: Monier arch bridge consisting of two, 13.2m spans, total effective span 28.5 m. A modern arch bridge has been erected in parallel to the original structure to widen Weeroona Avenue from two to four lane widths. The two bridges are joined with a simply supported reinforced concrete slab approximately 250mm to 400mm thick.

Second King's Bridge. View from the new archway to the existing Monier archway. The new reinforced concrete bridge mimics the old Monier Bridge; a testament to the design and a sensitive addition on a historically valuable site.
Image: Owen Peake.

Second King's Bridge. Concrete slab connecting the original Monier arch bridge to the newer arch bridge.
Image: Owen Peake.

Second King's Bridge. Depth of concrete used in Monier arch approximately 350mm, image details a sense of scale.
Image: Owen Peake.

3.1.15 Physical Condition: The piers, approaches and arches are in good condition. The abutments are in fair condition on the upstream side, erosion has occurred and should be reinstated before a protective geotextile is installed to prevent further erosion occurring. The modern addition on the downstream side has a protective geotextile to prevent erosion and to maintain uniformity. The same product should be installed on the upstream side.


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Second King's Bridge. Erosion at the North East Abutment, on upstream side of King's Bridge.
Image: Owen Peake.

Minor spalling on the underside of the arches is expected, as the original concrete cover and compaction was minimal. This damage should be repaired to protect the reinforcing steel however the damage is not considered serious in structural terms, as this reinforcement is virtually redundant in this design of bridge. Repairs have been made to the structure in the past and they appear to be successful in preventing further deterioration occurring when treated.

Second King's Bridge. The expansion of rust to the reinforcement caused the concrete to crack exposing the reinforcement bars. Treatment: remove the compromised concrete, sandblast the steel bars and reinstate the concrete to protect from further corrosion. The reinforcing mesh runs perpendicular through the concrete arch creating a diamond pattern internally. The existing concrete cover was 25mm-40mm.
Image: Owen Peake.

To prevent the build-up of water in the spandrel wall, the underside of the bridge has been bored with holes approximately 100mm in diameter to allow the water to drain out of the fill.

The City of Greater Bendigo has also marked the underside of the bridges with survey marks to analyse the movement of the existing King's Bridge as cracks have developed in the concrete arch span. This is to assess if movement in the abutments or settlement of the pier etc. is causing tension cracks in the structure.

3.1.16 Modifications and Dates: 14th May 1901 the Original Structure a Single span Monier Bridge failed under the testing load of a 14 ton steam roller and a 13 ton traction engine to simulate the expected load of a boiler (30 Tons). The inquiry into the bridge failure concluded that the heavy skew of the bridge and the severe load test caused the failure. Monash and Anderson undertook to rebuild the bridge at their own expense. The single span design was replaced with a two span Monier Bridge completed in 1902 to give a safer design.

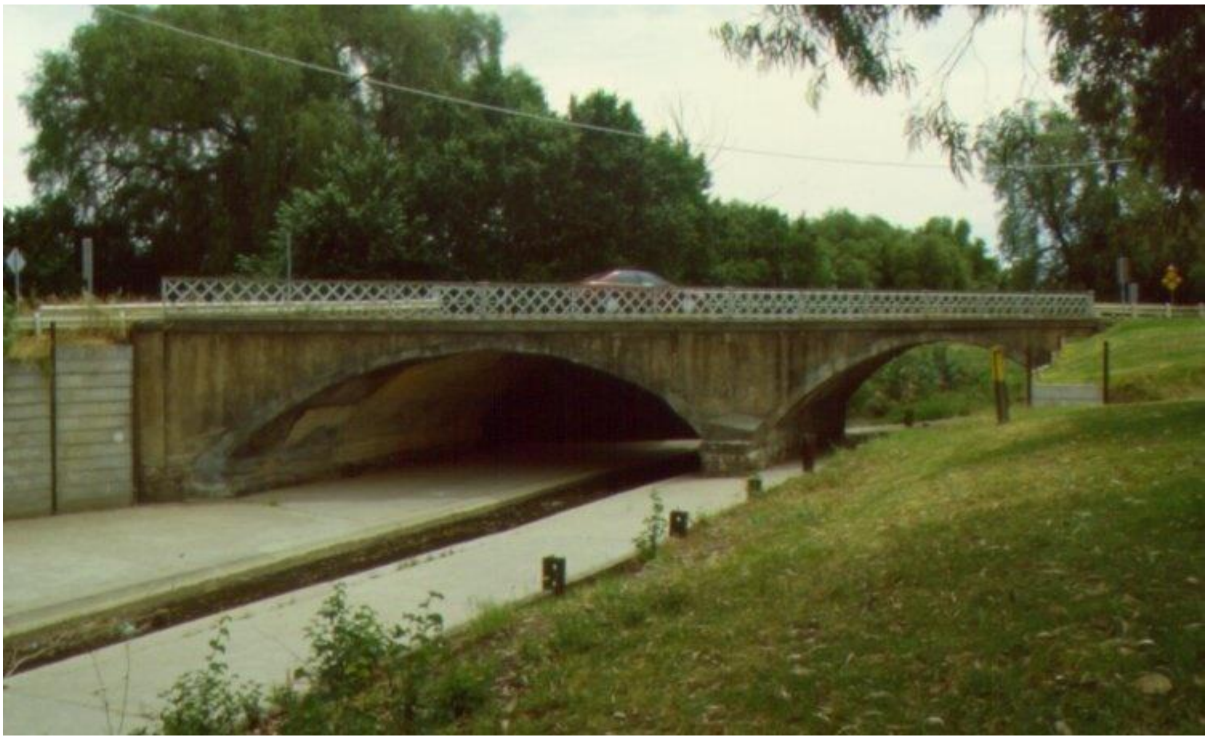
Reinforcement repairs and survey marks have been carried out over the life of King's Bridge to monitor the structural integrity of the original portion of King's Bridge, after the strengthening and widening of the original structure in 2004.

King's Bridge strengthening and widening completed 14th of May 2004,104 years after the original structure failed.

Second King's Bridge. Commemorative plaque to mark the reopening of King's Bridge.
Image: Owen Peake.

Second King’s Bridge. Widened 4 lane King’s Bridge.
Image: Owen Peake.

Second King’s Bridge. New arch bridge built to the same proportions as the existing King’s Bridge.
Image: Owen Peake.



Second King's Bridge. Original Monier Bridge before widening project.
Image: http://vhd.heritage.vic.gov.au/#detail_places;11176

Second King's Bridge. Remaining original wrought Iron fence and blue stone pillar. Note that the wrought iron balustrade was used to lighten the load on the edges of the arch instead of the original brick parapet.
Image: Owen Peake.

3.2. Item Name: Abbott Street Bridge [on Back Creek/Spring Creek[1]]

Abbott Street Bridge. Jan 2014.
Image: Owen Peake.

Abbott Street Bridge. Original 2 lane road width.
Image: Owen Peake.

[1] The Creek has two names; Back Creek and Spring Creek.

3.2.1 Other/Former Names: Unknown
3.2.2 Location: Abbott Street between Havlin Street East and Havlin Street West
3.2.3 Address: As above
3.2.4 Suburb/Nearest Town: Bendigo
3.2.5 State: Victoria
3.2.6 Local Govt. Area: City of Greater Bendigo
3.2.7 Owner: City of Greater Bendigo
3.2.8 Current Use: Road Bridge (including pedestrian and bike)
3.2.9 Former Use: Road Bridge (including pedestrian and bike)
3.2.10 Designer: Monash and Anderson, Melbourne
3.2.11 Maker/Builder: Monash and Anderson, Melbourne
3.2.12 Year Started: 1900
3.2.13 Year Completed: 1901
3.2.14 Physical Description: Monier arch bridge consisting of a single span, two lane width.
3.2.15 Physical Condition: The piers, abutments, approaches and arches are in good condition.

Minor spalling on the underside of the arches is expected, as the original concrete cover was minimal. This damage should be repaired to protect the reinforcing steel however the damage is not considered serious in structural terms, as this reinforcement is virtually redundant in this design of bridge. Repairs have been made to the structure in the past and they appear to be successful in preventing further deterioration occurring when treated.

The spandrel walls have moved outwards because of internal pressure from the fill, and the parapet walls have been displaced by the movement of the spandrel walls. The movement of the parapet walls has the effect of opening a gap between the road pavement and the wall, which in turn leads to water entering the spandrel fill. This is a vicious circle of cause and effect as the fill is apparently expanding when wet. To prevent the build-up of water in the spandrel wall, the underside of the bridge has been bored with holes approximately 100mm in diameter to allow the water to drain out of the fill.

The City of Greater Bendigo has marked the underside of the bridges with survey marks to analyse the movement of the existing Bridge as cracks have developed in the concrete arch span. This is to assess if movement in the abutments or settlement of the pier etc. is causing tension cracks in the structure or change in the shape of the concrete arch.

3.2.16 Modifications and Dates: No major repairs are known to have been carried out in the last 113 years.

3.3 Item Name: High Street Bridge [Calder Highway]

High Street Bridge. Jan 2014.
Image: Owen Peake.

3.3.1 Other/Former Names: High Street
3.3.2 Location: High Street
3.3.3 Address: As above
3.3.4 Suburb/Nearest Town: Bendigo
3.3.5 State: Victoria
3.3.6 Local Govt. Area: City of Greater Bendigo
3.3.7 Owner: VicRoads
3.3.8 Current Use: Road Bridge (including pedestrian and bike)
3.3.9 Former Use: Road Bridge (including pedestrian and bike)
3.3.10 Designer: Monash and Anderson, Melbourne
3.3.11 Maker/Builder: Monash and Anderson, Melbourne
3.3.12 Year Started: 1900
3.3.13 Year Completed: 1901
3.3.14 Physical Description: Monier arch bridge, four lane, single span
3.3.15 Physical Condition: The piers, abutments, approaches and arches are in good condition.

Minor spalling on the underside of the arches is expected, as the original concrete cover was minimal.

The spandrel walls have moved outwards because of the internal pressure from the fill, and the parapet walls have been displaced by the movement of the spandrel walls. The movement of the parapet walls has the effect of opening a gap between the road pavement and the wall, which in turn leads to water entering the spandrel fill. This is a vicious circle of cause and effect as the fill is apparently expanding when wet. To prevent the build-up of water in the spandrel

wall, the underside of the bridge has been bored with holes approximately 100mm in diameter to allow the water to drain out of the fill.

The City of Greater Bendigo has marked the underside of the bridges with survey marks to analyse the movement of the existing Bridge as cracks have developed in the concrete arch span. This is to assess if movement in the abutments or settlement of the pier etc. is causing tension cracks in the structure or change in the shape of the concrete arch.

3.3.16 Modifications and Dates: No major repairs are known to have been carried out in the last 113 years.

3.4 Item Name: Thistle Street Bridge

Thistle Street Bridge. Jan 2014.
Image: Owen Peake.

Thistle Street Bridge. Note slight downward deflection at the centre of the span. Jan 2014. ***Image: Owen Peake.***

Thistle Street Bridge.
Image: Owen Peake Jan 2014.

Thistle Street Bridge. Water stains the side of the bridge as it seeps out of infill.
Image: Owen Peake Jan 2014.

3.4.1 Other/Former Names: None
3.4.2 Location: Thistle Street
3.4.3 Address: As above
3.4.4 Suburb/Nearest Town: Bendigo
3.4.5 State: Victoria
3.4.6 Local Govt. Area: City of Greater Bendigo
3.4.7 Owner: City of Greater Bendigo
3.4.8 Current Use: Road Bridge (including pedestrian and bike)
3.4.9 Former Use: Road Bridge (including pedestrian and bike)
3.4.10 Designer: Monash and Anderson, Melbourne
3.4.11 Maker/Builder: Monash and Anderson, Melbourne
3.4.12 Year Started: 1900
3.4.13 Year Completed: 1901
3.4.14 Physical Description: Monier arch bridge, singe span, two lanes.
3.4.15 Physical Condition: The piers, abutments, approaches and arches are in good condition.

Minor spalling on the underside of the arches is expected, as the original concrete cover was minimal.

The spandrel walls have moved outwards because of the internal pressure from the fill, and the parapet walls have been displaced by the movement of the spandrel walls. The movement of the parapet walls has the effect of opening a gap between the road pavement and the wall, which in turn leads to water entering the spandrel fill. This is a vicious circle of cause and effect as the fill is apparently expanding when wet. To prevent the build-up of water in the spandrel wall, the underside of the bridge has been bored with holes approximately 100mm in diameter to allow the water to drain out of the fill.

The City of Greater Bendigo has marked the underside of the bridges with survey marks to analyse the movement of the existing Bridge as cracks have developed in the concrete arch span. This is to assess if movement in the abutments or settlement of the pier etc. is causing tension cracks in the structure or change in the shape of the concrete arch.

3.4.16 Modifications and Dates: No major repairs are known to have been carried out in the last 113 years.

3.5 Item Name: Booth Street Bridge

Casting the deck of the Booth Street Bridge.
Image: Melbourne University Archives.

Testing of completed Booth Street Bridge.
Image: Melbourne University Archives.

Booth Street Bridge, upstream side.
Image: Owen Peake Jan 2014.

Booth Street Bridge, Jan 2014 downstream side.
Image: Owen Peake.

3.5.1 Other/Former Names: None
3.5.2 Location: Booth Street
3.5.3 Address: As above
3.5.4 Suburb/Nearest Town: Bendigo
3.5.5 State: Victoria
3.5.6 Local Govt. Area: City of Greater Bendigo
3.5.7 Owner: City of Greater Bendigo
3.5.8 Current Use: Road Bridge (including pedestrian and bike)
3.5.9 Former Use: Road Bridge (including pedestrian and bike)
3.5.10 Designer: Monash and Anderson, Melbourne
3.5.11 Maker/Builder: Monash and Anderson, Melbourne
3.5.12 Year Started: 1900
3.5.13 Year Completed: 1901
3.5.14 Physical Description: Monier arch bridge, single span, 2 lanes.
3.5.15 Physical Condition: The piers, abutments, approaches and arches are in good condition.

Minor spalling on the underside of the arches is expected, as the original concrete cover was minimal.

The spandrel walls have moved outwards because of the internal pressure from the fill, and the parapet walls have been displaced by the movement of the spandrel walls. The movement of the parapet walls has the effect of opening a gap between the road pavement and the wall, which in turn leads to water entering the spandrel fill. This is a vicious circle of cause and effect as the fill is apparently expanding when wet. To prevent the build-up of water in the spandrel wall, the underside of the bridge has been bored with holes approximately 100mm in diameter to allow the water to drain out of the fill.

The City of Greater Bendigo has marked the underside of the bridges with survey marks to analyse the movement of the existing Bridge as cracks have developed in the concrete arch span. This is to assess if movement in the abutments or settlement of the pier etc. is causing tension cracks in the structure or change in the shape of the concrete arch.

3.5.16 Modifications and Dates: No major repairs are known to have been carried out in the last 113 years.

3.6 Item Name: Wade Street Bridge

Wade Street Bridge.
Image: Owen Peake Jan 2014.

Wade Street Bridge, looking downstream.
Image: Owen Peake Jan 2014.

Wade Street Bridge. Weeds can be seen infiltrating the bridge.
Image: Owen Peake Jan 2014.

3.6.1 Other/Former Names: Wade Street Bridge
3.6.2 Location: Wade Street
3.6.3 Address: As above
3.6.4 Suburb/Nearest Town: Bendigo
3.6.5 State: Victoria
3.6.6 Local Govt. Area: City of Greater Bendigo
3.6.7 Owner: City of Greater Bendigo
3.6.8 Current Use: Road Bridge.
3.6.9 Former Use: Road Bridge (including pedestrian and bike)
3.6.10 Designer: Monash and Anderson, Melbourne
3.6.11 Maker/Builder: Monash and Anderson, Melbourne
3.6.12 Year Started: 1900
3.6.13 Year Completed: 1901
3.6.14 Physical Description: Monier arch bridge, single span, 2 lanes
3.6.15 Physical Condition: The piers, abutments, approaches and arches are in good condition.

Minor spalling on the underside of the arches is expected, as the original concrete cover was minimal.

The spandrel walls have moved outwards because of the internal pressure from the fill, and the parapet walls have been displaced by the movement of the spandrel walls. The movement of the parapet walls has the effect of opening a gap between the road pavement and the wall, which in turn leads to water entering the spandrel fill. This is a vicious circle of cause and effect as the fill is apparently expanding when wet. To prevent the build-up of water in the spandrel wall, the underside of the bridge has been bored with holes approximately 100mm in diameter to allow the water to drain out of the fill.

The City of Greater Bendigo has marked the underside of the bridges with survey marks to analyse the movement of the existing Bridge as cracks have developed in the concrete arch span. This is to assess if movement in the abutments or settlement of the pier etc. is causing tension cracks in the structure or change in the shape of the concrete arch.

3.6.16 Modifications and Dates: No major repairs are known to have been carried out in the last 113 years.

3.7 Historical Notes

3.7.1 Requirement for bridges

A major opportunity to exploit the Monier patent occurred when it was decided to control flooding and silting in the Bendigo Creek by building a concrete-lined channel through the City, requiring the replacement of a number of bridges. The City Engineer, J. R. Richardson, had prepared designs for these using the conventional technique of steel girders resting on masonry supports and carrying a timber deck. Amongst them was King's Bridge, planned to carry what was then White Hills Road across the 18.3m wide channel at an extreme angle, or 'skew'.

3.7.2 Preliminaries and Negotiations

Monash and Anderson realised at once that a Monier arch for this particular location would not compete in price with Richardson's version. It was contemporary practice, for design and analysis, to imagine a masonry arch cut into vertical slices and to investigate the theoretical stability of each independently of its neighbours. In the case of a skew arch, the slices were imagined cut parallel to the parapets, along the skew. This made the effective span of King's

Bridge relatively large, at about 28.5m. To make matters worse, the need to provide clearance for floodwaters demanded high springings, resulting in a relatively flat arch. This combination of factors would result in large internal forces for which a thick vault and heavy abutments would have to be provided.

During negotiations, Richardson had added several stipulations to the standard form of contract. Most importantly he had decided that King's Bridge, situated on the main route north through Bendigo, must be able to withstand the weight of 30-ton boilers which might be transported to mines in the region. He therefore specified that it be tested by the combined weight of a steam roller and a traction engine, both weighing 15 tons. This was double the normal requirement.

M&A exercised the Victorian rights to the Monier patent under licence to the Sydney firm, at that time named Gummow Forrest & Co. It was understood they would assiduously promote and maintain the reputation of the Monier system and that they had a right to, and would accept, GF & Co's advice on technical matters.

3.7.3 Construction and Testing

Foundation conditions at King Street were not ideal. Much of the abutments were founded on "stratified pipe clay". By 17 January 1901 both abutments had been concreted to springing level.

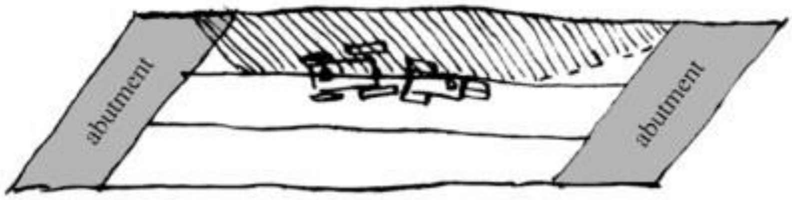
The forming of the arch itself was to be done in three parallel strips, each cast in a single day from one abutment to the other.

On 14 May Richardson and a team of Council employees assembled to conduct the test. Anderson was engaged on other work and Monash represented the partnership. The council workers installed simple instruments (extensometers) under the bridge to measure deflection due to the test load. Richardson first instructed the Council roller driver to compact the newly laid road surface. The roller made twelve passes, but avoided the extreme northern (downstream) edge where a water main had been laid within the fill. The roller and traction engine were then both placed on the bridge so that Monash could take photographs. After this, preparations were made to conduct the formal test, with council workers going under the bridge to record the readings of the extensometers. It was then noticed that a fine crack had developed in the soffit of the downstream strip near the crown, running across its full width and extending into the centre strip. There were signs of distress in other locations and the extensometers were already indicating some permanent deflection.

Richardson, Monash and others examined the bridge but Richardson decided it was safe to proceed with the test. There is no record of Monash having made any attempt to dissuade him. This may seem strange, but both engineers would have known of European tests of prototype Monier arches in which the load required to cause failure had been three times that at which the first signs of distress appeared. Monash was convinced that all cracks were superficial and that the bridge would never again be subjected to anything like its present load. As the test continued the roller and traction engine were brought close together near mid-span on two occasions while readings were taken from the extensometers by men standing under the arch. After some consideration, Richardson decided that the test had not been sufficiently severe, as most of the weight of the engines was concentrated on their back axles and so far they had been placed in tandem. He ordered the traction engine to leave the bridge, turn round and back up to the roller near mid-span to bring its rear axle close to that of the roller, thus simulating his 30 ton concentrated load.

The machines were placed mainly over the middle strip, but each had two wheels on one side resting on the downstream strip. The diagram below, adapted from one prepared by Professor

Kernot, shows the three strips spanning between the west and east abutments, the positions of the traction engine and roller, and the portion of the northern strip which collapsed (shaded).



As the council workers took up positions under the bridge for further readings it was noticed that deflection was increasing at an alarming rate. Pieces of mortar could be heard dropping from the crack and splashing into the water. There were shouts of warning and a scramble to get clear. Those on top of the bridge felt the downstream strip starting to give way. The crew of the traction engine managed to jump clear of their machine, but descended with the arch as did a group including Richardson, which had been on top of the bridge. The concrete of the downstream strip separated from that of the middle strip, leaving a clean face. The lower lateral reinforcing rods, which had extended some way into the middle strip were ripped out, while the downstream spandrel wall and parapet were thrown into the channel. The roller remained precariously perched on the edge of the middle strip but the traction engine fell sideways into the channel. Its fall killed A. E. Boldt, a business associate of its owner, who had been next to it looking over the parapet. Surprisingly, considering the jumble of concrete, bricks, coping blocks and men that had been projected through the air, he was the only casualty.

3.7.4 Investigation, Legal Inquest, Solution and Re-design

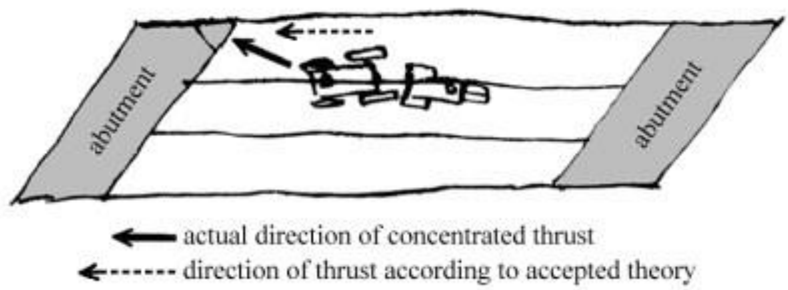
Monash and Anderson were mystified by the collapse. They were sure of their calculations and of the quality of materials and workmanship. In commercial terms the situation was critical, as the disaster threatened to bring the Monier system into disrepute throughout Victoria and deprive M&A of future highly profitable work. The partners could only assume that some hitherto unsuspected technical problem was to blame, and retained W. C. Kernot, Professor of Engineering at the University of Melbourne, to investigate on their behalf. One possibility was that there was something wrong with the above-mentioned conventional method of analysing skew arches.

In searching for a more rigorous alternative, Kernot consulted leading mathematicians, but it was agreed that the mechanics of the skew arch were beyond their capabilities. Attention then turned to small-scale physical models, to gain some understanding by observing their deformation under load.

One of Kernot's brothers, W N Kernot, a lecturer in electrical engineering at the Working Men's College (later RMIT and now RMIT University), studied the flow of electricity through a metal sheet cut to the shape of the arch, exploiting the fact that the equations governing distribution of electrical potential are similar to those governing intensity of stress.

Although they could not give accurate figures, these studies showed that in a skew arch the internal thrust would tend to concentrate along the shorter diagonal (looking in plan). In the case of King's Bridge, with its high angle of skew and high span-to-width ratio, the actual stresses would be more than four times those calculated by the conventional method.

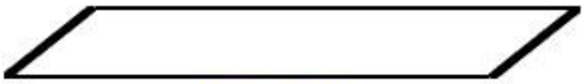
Observation of the ruins of King's Bridge and tests made on samples of material suggested that while the concrete of the arch could withstand even the heightened stresses, however the abutment concrete, with its lower proportion of cement, had been unable to do so and had been crushed allowing the arch ring to fall.



Kernot presented this evidence to the inquest with the aid of a blackboard and assured the jury that every text-book he could lay his hands on, including the great Rankine's, advocated the conventional approach.

The Bendigo jury evidently decided that the designers and builders in this case had acted reasonably and could not have been expected to foresee the problem despite the high quality of their work, materials, approach and acting in good faith using the currently accepted theories of the time. The verdict was that Boldt had met his death accidentally, "and that no blame can be attached to anyone".

M&A now turned to the challenge of re-designing the bridge. M&A therefore decided to retain the existing abutments and build a new pier in midstream so that the bridge would consist of two arches each of 13.2m span rather than one of 28.5m. This would reduce the calculated thrust on the abutments to little more than a quarter of the value for the single arch. Also, the ratio of skew-span to width would be reduced by more than half, and the abutments of each arch would be situated more directly opposite each other.



Plan of KB1

Plan of KB2

The second King Street Bridge was completed and tested satisfactorily. It remains in service to this day. The other bridges in the group did not have the high skew of King Street and presented little difficulty. As previously mentioned six of the original crossings remain in service today and are maintained for service by the City of Greater Bendigo.

3.7.5 Retrospective View of King St Failure

In modern society, an error of this magnitude, resulting in deaths and injuries, would likely carry more severe consequences than those experienced by Monash and Anderson. In modern day case studies, there have been legal proceedings that resulted in compensations and the stripping of engineering licenses for negligence and professional misconduct. Additionally, these case studies now serve as examples of ethics, risks and disaster management.

The disaster at the King Street Bridge highlights the difference in approach over the course of almost a century. Although the conventional theory used in Monash and Anderson's King Street bridge design was thought to be acceptable and adequate, it is not an infallible defence. Although the design is similar, no testing of a design feature not previously implemented could be regarded as questionable. Additionally, with a bit more care and methodical approach, on the day of the test, the disaster could have even been avoided. In a modern and conservative age where emphasis is placed on safety and standards and resources are plentiful and well

researched, a similar occurrence is still possible and could hold a very different legal outcome even if the accepted theories are considered inadequate.

Regardless of the legal consequences that would result in a project that causes injury or death, it is an important note that engineering is not always successful and is in a constant state of flux where a contemporary engineer's confidence can be tested and lessons can be learned from failures and a subsequent solution found.

3.8 Heritage Listings

The King Street Bridge on Bendigo Creek in Bendigo has several heritage listings:

3.8.1 Victorian Heritage Register

Name: King Street Bridge, Bendigo
Level: State
Register Number: H1935
Date Classified: 02/10/2000

3.8.2 National Trust of Australia (Victoria)

Name: King Street Bridge, Bendigo
Level: State
Register Number: B7071
Date Classified: 02/10/2000

3.8.3 City of Greater Bendigo Heritage Overlay

Name: King Street Bridge, Bendigo
Level: State
Heritage Overlay Number: H0580
Date Classified: 02/10/2000

4 Assessment of Significance

4.1 Historical Significance

See section 3.18 above for details of the history of the Bendigo Monier Arch Bridges.

The particular significance of these sites lies in their place in the evolution of bridge building materials and methods.

Following the construction of 18 Monier arch bridges by Monash and Anderson in Victoria the style of bridge changed to reinforced concrete girder bridges from about 1910 onwards. This technique remains the most popular type of construction of road bridges until the present day with some refinements such as the prefabrication of bridge beams.

Hence, the Monier bridges can be said to stand at the change from predominantly masonry or timber bridges to reinforced concrete road bridges in Victoria. This evolution of bridge construction to reinforced concrete allowed road authorities to build more robust bridges with very long life and at relatively low capital and maintenance costs.

Furthermore the designs of Carter Gummow and Co and Monash & Anderson have stood the test of time. Many of their Monier bridges are still in service more than a century after they were built. Whilst there was evolutionary change in the design of reinforced concrete structures we can now see the early Carter Gummow and Co and Monash and Anderson bridges provided a very firm basis on which bridge design and construction in the 20th century was built.

4.2 Historic Individuals or Association

See Appendix 2 for biographical information on:

1. John (later General Sir John) Monash
2. Joshua T N Anderson
3. Joseph Monier
4. Dr Alan Holgate

4.3 Creative or Technical Achievement

About half of all the Monier reinforced concrete arch bridges built in Victoria were built in the Bendigo group between 1901 and 1902.

The group includes the ill-fated King’s Bridge, which collapsed under test. This event enabled engineers to better understand the structural problems of extremely skewered bridges and to find ways to adequately analyse them structurally. It seems that Monash and Anderson did not make an error in the design of the original King’s Bridge. However, the engineering understanding of skewed bridges was not adequate at the time. Monash & Anderson changed this and increased the understanding of the forces involved in skewed bridges.

The construction of the Monier bridges also caused Monash & Anderson to think further about the use of reinforced concrete in bridges. Within a decade after this group of bridges were constructed in Bendigo, Monash & Anderson had developed the concept of the “T” girder for reinforced concrete bridges. This type of design has endured and with the later introduction of pre and post stressing has become the “standard” design for small to medium reinforced concrete bridges during the last century. It is, perhaps, this achievement which we should celebrate the most. Today, bridge engineers throw bridges across roads and railways with little design input using standard “T” beams which can be mass-produced at a low cost and which have proven to be extremely robust and long-lived.

Part of the robustness and longevity of concrete bridges lies in their resistance to the effect of bushfires. In the early years of development of the Victorian road system the greatest damage to bridges was caused by bushfires. The reinforced concrete bridge removed that particular vulnerability.

Whilst we celebrate the wonderful old Monier bridges for their ingenuity and elegance, we drive every day over dozens of unremarkable but highly utilitarian “T” beam bridges. Therein lies the great achievement of Monash. To fully understand this enduring achievement we need to look at his great “T” beam bridges, such as the Janevale Bridge.

4.4 Research Potential

Considerable work has been done by researchers such as P F B Alsop and Alan Holgate on the work of Monash and Anderson. No particular areas for further research appear to be pressing however as new material is found further research will undoubtedly occur. For instance in 2012 intelligence came to light suggesting that a cabinet full of Monash & Anderson drawings, not previously known of, and not currently in the public arena have been found. Careful scrutiny of these drawings may throw more light on the designs, methods and contractual issues relating to the work of the partnership.

4.5 Social:

The early 20th century saw a very rapid expansion of the road network in Victoria. This expansion led to the construction of very large numbers of bridges. When the Country Roads Board was formed in 1913 it quickly started to standardise bridge design to allow the more rapid expansion of the road network.

The work of expanding the road network was fundamental to the social changes relating to the adoption of the motor car which started at the turn of the 20th century and accelerated rapidly after the Second World War. This was one of the most profound social changes of the 20th century, leading most families to own at least one car by the 1960s.

The bridges of the Victorian road network, most of them quite modest in size, were critical to the achievement of this social change. The key issue for this story is that most of these bridges were built of reinforced concrete which proved to be cheap, durable and resistant to fire damage. The Monash & Anderson Monier bridges mark the beginning of reinforced concrete bridges in Victoria and for this reason they should be recognised and preserved as an important part of our engineering heritage.

4.6 Rarity

Monash & Anderson built 18 Monier arch bridges in Victoria between 1899 and 1913. 11 of these bridges survive, at least 4 have been demolished and a further 3 are uncertain. It cannot therefore be said that these bridges are rare.

More importantly we need to work to ensure that the remaining bridges are maintained, preserved and protected.

4.7 Representativeness

This group of bridges are “typical” of Monier bridges built by Monash & Anderson. The group of bridges is coherent in that (apart from King’s Bridge) they are very similar in size and design. What is really nice about these bridges is that this coherent group is within a stone’s throw of one another and predominantly on the same creek [2].

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[2] With the Exception of Abbott Street Bridge crossing Back Creek/Spring Creek.

4.8 Integrity/Intactness

The bridges appear virtually as first constructed.

To prevent the build-up of water in the spandrel wall, the underside of the bridges have been bored with holes approximately 100mm in diameter to allow the water to drain out of the fill.

The City of Greater Bendigo has also marked the underside of the bridges with survey marks to analyse the movement of the existing King's Bridge as cracks have developed in the concrete arch span. This is to assess if movement in the abutments or settlement of the piers is causing tension cracks in the structure.

A modern arch bridge has been erected in parallel to the original structure to widen Weeroona Avenue from two to four lane widths. The two bridges are joined with a simply supported reinforced concrete slab approximately 250mm to 400mm thick.

The widening of the original King's Bridge resulted in the removal of the existing wrought Iron and blue stone balustrade on the downstream side of the bridge.

5 Statement of Significance

5.1 National Trust of Australia (Victoria) [3]

"Weeroona Avenue Bridge over Bendigo Creek

The 1901 two-span reinforced concrete arch bridge is of scientific and historical significance at the State level.

It has scientific significance as an extraordinary example of the Monier arch bridges designed and constructed by Monash & Anderson. Although similar in design and construction to the single span bridges built in Bendigo at the same time, this bridge is of two spans and has an unusually high 50 degree skew, the highest for any Monier span in Australia, and possibly the world. This two span bridge represents a resourceful response to the problems of the site following the catastrophic failure of the firm's single span design originally built on the site, which had pushed the boundaries of the new reinforced concrete technology. The bridge demonstrates an important stage in the firm's achievements in the development of reinforced concrete technology, and in early twentieth century engineering.

It has historical significance as one of six bridges surviving from a group of eight related bridges that are associated with Bendigo's early twentieth century drainage system and urban improvements. It demonstrates enhanced significance as one of the group. It also demonstrates the Bendigo Borough Council's confidence in the new technology of the time. It also has historical significance as one of the early achievements of John Monash, later Sir John Monash, who played an important role in the early development of reinforced concrete design and construction in Victoria before he achieved fame as Australia's most distinguished World War One general, and first General Manager of Victoria's State Electricity Commission".

5.2 Heritage Victoria [4]

"The Weeroona Avenue Bridge was one of eight Monier concrete arch bridges constructed by Monash & Anderson for the City of Bendigo during 1900-02. Designed by Sydney engineers Gummow Forrest & Co, in conjunction with Monash & Anderson, this two span bridge replaced an earlier single span Monier arch bridge built at this site by Monash & Anderson which failed during load testing. The abutments of the original bridge were re-used in the second bridge. The bridge has an unusually high skew of 50 degrees, and the span of the arches measured along the skew is 13.2 metres. The rise of each arch is 2.6 metres, and the width of the roadway between parapets is 7.3 metres. The spandrels are of rendered brickwork, and the southern (upstream) side of the bridge retains the original balustrade, a lattice of wrought iron flats with brick newel posts.

The Weeroona Avenue Bridge is of scientific importance as an extraordinary example of the Monier concrete arch bridges designed and constructed by Monash & Anderson, and demonstrates an important stage in the development of reinforced concrete technology and early twentieth century engineering. It represents a resourceful response to the problems of the site following the failure of the firm's single span bridge, which had pushed the boundaries of the new reinforced concrete design and construction. The unusually high skew of the bridge is rare, and the use of wrought iron lattice balustrades is demonstrable evidence of Monash's attempt to lighten the load on the edges of the arch following the collapse of the first bridge which had heavy brick balustrades.

[3] Extracted from the National Trust of Australia (Victoria) web page on 15 March 2013.

[4] Extracted from Heritage Victoria web page on 4 February 2014.

The Weeroona Avenue Bridge has historical significance for the active involvement of (Sir) John Monash in its design and construction, and of the important role that it, and its failed predecessor, played in the development of his career. It also has historical importance in demonstrating the Bendigo Council's enterprise and confidence in adopting new technology for its early twentieth century drainage system and urban improvements".

5.3 Register of the National Estate (now downgraded to a non-statutory archive) None found

6 Level of Significance

State

7 Interpretation Plan

7.1 Interpretation Strategy

The strategy for interpretation of the Engineering Heritage Works is laid out in the latest version of EHA's "Guide to the Engineering Heritage Recognition Program" [5]. The interpretation will be by marking the works with an appropriate level of heritage marker; a public ceremony to unveil that marker; and an interpretation panel which summarises the heritage and significant features of the works for the public.

This plan provides a summary of the proposals for design, content, location, manufacture and funding of the proposed interpretation.

7.2 Event Date

The ceremony should be held on **Saturday 9 August 2014** at a time to be fixed.

7.3 The Interpretation Panels

It is proposed to erect two panels:

1) At King's Bridge (Weeroona Avenue)
2) Near the High Street/Booth Street/Wade Street group of bridges. This will be termed the "Old High Street" panel where it is proposed to be placed.

The following will be incorporated into the design of the King's Bridge panel:

1) A title: **"King's Bridge"**.
2) A subtitle: **"Disaster at King's Bridge"**.
3) Logos of Engineers Australia and City of Greater Bendigo.
4) A small-scale representation of the EHA marker plate.
5) The date and other details of the marking ceremony.
6) A web site reference to the availability of the full nomination on the EHA web page.
7) A QR code to the above reference.
8) Text for main text panels should be 30-point Arial Bold.
9) Minimum text size should be 24-point Arial Bold.
10) A map showing the group of bridges in Bendigo
11) Historic photographs will be used to illustrate the panel. Many historic photographs exist. Brief captions and source references to accompany each photograph.

[5] The 2012 version. It should be noted that this version is not available on the Engineers Australia website at the time of writing.

The following will be incorporated into the design of the Old High Street panel:

1) A title: **"Monier Arch Bridges in Bendigo".**
2) A subtitle: **"Early Use of Reinforced Concrete in Victoria"**.
3) Logos of Engineers Australia and City of Greater Bendigo.
4) A small-scale representation of the EHA marker plate.
5) The date and other details of the marking ceremony.
6) A web site reference to the availability of the full nomination on the EHA web page.
7) A QR code to the above reference.
8) Text for main text panels should be 30-point Arial Bold.
9) Minimum text size should be 24-point Arial Bold.
10) A map showing the group of bridges in Bendigo
11) Historic photographs will be used to illustrate the panel. Many historic photographs exist. Brief captions and source references to accompany each photograph.

The interpretation panels will technically be constructed and erected as follows:

1) Size to be nominally 1200 mm wide by 600 mm high.
2) The panels to be constructed of vitreous enamel-on-steel plate with flanges as per drawing at Appendix 8.
3) The panel to be mounted on a steel freestanding frame as per Appendix 8.
4) The EHA marker (Engineering Heritage Marker) to be mounted below the interpretation panel as shown in Appendix 8.

The location of the interpretation panels has not yet been agreed with the City of Greater Bendigo Council, owner of the land on which they will be erected. However the present plan for location of the two panels is:

1) At the King's Bridge:

In a small park area on the creek bank near a large peppercorn tree on the side of Weeroona Avenue opposite the lake at the south-western end of the bridge (closest to Caledonia Street)

2) At the Old High Street site:

On the southern side of Old High Street facing the creek between the Booth Street Bridge and the High Street (Calder Highway) bridge. This location will provide a simultaneous view of the three similar bridges (High Street, Booth Street and Wade Street).

These locations are safely clear of high traffic areas, give good views of the bridges and should not create any unacceptable obstructions for Council maintenance.

The panels will be mounted so that the bridges are in full view when the observer looks up from reading the interpretation panel.

The marker will be mounted on the crossbar of the interpretation panel stand and measures will be taken to secure them against removal by vandals.

7.4 Design Process for the Panel Content

The following parties will review the nomination during its development:

1) The ten members of the committee of Engineering Heritage Victoria
2) Mr Richard Venus, who is also the selected professional graphic designer for the project.
3) Mr Andrew Long who is acting as civil engineering Mentor for the students writing the nomination.

The design of the interpretation panels will be developed to the initial concept stage as part of the nomination writing process. It will then be further developed to a draft panel status by Richard Venus followed by review by the above reviewers plus the Heritage Recognition Committee and the site owner.

Manufacture will then be carried out by Glass Metal Industries, subject to availability of sufficient funding with the fall-back position being manufacture using vinyl film on aluminium by Advanced Group, Melbourne.

7.5 Funding

Funding for the interpretation panels is expected to be required as follows:

Item	Fund Source	Amount
Graphic Design including purchase of photographic rights	EHA National Budget	2 x $500 = $1000
Manufacture of panel by Glass Metal Industries	To be arranged	2 x $1400 = $2800
Manufacture of Steel Stand	To be arranged	2 x $1000 = $2000
Installation of panel stand and panel	To be arranged	2 x $500 = $1000
Supply from stock of marker by EHA	EHA National Budget	2 x $300 = $600
	TOTAL	$7400

7.6 Draft Interpretation themes for Interpretation Panels

In accordance with good interpretation practice the content of the panels should be divided into three or four themes for ease of understanding by the public. The following have been assessed as possible themes/sub-themes for the interpretation panels:

The King’s Bridge Panel:

a) List and Map of the Bendigo Bridges
b) One arch or two
c) How did it happen?
d) The New King’s Bridge
e) The Bendigo Creek

Total text should not exceed 500 words excluding headings.

Old High Street Panel:

a) The role of John Monash and Joshua Anderson
b) List and Map of the Bendigo Bridges
c) Why an arch bridge?
d) Building the Bendigo Bridges
e) From Pots to Ponts (The development of Monier arch bridges)

Total text should not exceed 500 words excluding headings.

7.7 Preliminary Text Blocks for Interpretation Panels

The King's Bridge Panel:

Bendigo Bridges

Eight Monier arch bridges were built along the Bendigo Creek in 1901 to 1902 using a new material - reinforced concrete. Six are still in use today.

One Arch or Two?

Originally all eight bridges were designed as wide single arch structures. Following a shocking accident at the King's Bridge when a section of the arch collapsed during the load test - killing a contractor, Albert Boldt - the bridge was redesigned to have two spans and a central supporting pier, reducing stresses in the arches.

How did it happen?

Once a bridge was finished, its ability to safely carry loads was tested by driving heavy vehicles over it. The bridge was closely observed for any problems and a machine called an extensometer was used to check any movements.

At King's Bridge, a steam roller and a traction engine were used for the test - together they weighed 30 tons which was far in excess of the load limit of 25 tons.

When the two vehicles were in the middle of the bridge, one section collapsed. The traction engine fell into the creek bed, dragging Mr Boldt with it and crushing him.

Monash & Anderson could not understand why the bridge had failed and engaged Professor William Kernot from Melbourne University to investigate. He concluded that the large angle of skew had produced four times the expected stress in the bridge. Even with today's computers, engineers would find it difficult to analyse such an unusual structure.

The New King's Bridge

The two-span Monier arch bridge still carries traffic today. Alongside it is a new reinforced concrete arch bridge built in 2004. The road (now called Weeroona Avenue) was widened and a new road surface laid. However, from underneath, the two supporting structures can be clearly seen. The new King's Bridge was opened on 14 May 2014.

The Bendigo Creek

Sludge from the mines had been allowed to run into Bendigo Creek, filling up the creek bed which often caused floods. Engineers recommended clearing the sludge (which still contained some gold), realigning the creek and protecting the banks with timber sheeting. Mines also had to better manage their tailings. After years of delay, work finally began on the creek in May 1999.

370 words

The Old High Street Panel:

Monash & Anderson

Wheelers Bridge was designed and partially built by Melbourne consulting engineers Monash & Anderson who started in 1894.

General Sir John Monash (1865 - 1931)

In 1905 John Monash started the Reinforced Concrete & Monier Pipe Construction Company, which continued to develop the use of reinforced concrete in Victoria. Following a brilliant military career in World War I he became Chairman of the State Electricity Commission of Victoria and led the effort to use Latrobe Valley brown coal to generate electricity.

Joshua Anderson (1865 - 1949)

Joshua Anderson's engineering career has been overshadowed by Monash's military fame. Anderson worked in various disciplines, then went to New Zealand, and later worked as a municipal and consulting engineer in Victoria.

Why an Arch Bridge?

The graceful curve of an arch bridge transfers some of the weight of the bridge and its traffic into a horizontal force resisted by the abutments. Longer bridges may have several arches supported by piers in the middle.

People have been building arch bridges for thousands of years. They're simple, they work, and they can be quite pleasing in appearance.

To build a Monier arch bridge, timber formwork was erected and steel reinforcement put in place. The concrete was poured into the form – in 1899 they used wheelbarrows. When the concrete had gained sufficient strength the formwork was removed.

Building the Bendigo Bridges

Bendigo Creek, which runs through the centre of the city, was subject to sudden floods. In the 1890s the city obtained a loan from the Government to straighten and line the creek and build eight bridges (one over Back Creek, now Spring Creek). The bridges were built between 1901 and 1902. The King's Bridge (now Weeroona Avenue) failed during its load test and had to be rebuilt – see story at Weeroona Avenue.

From Pots to Ponts

French horticulturalist Joseph Monier devised a method of making flower pots and garden furniture using a mesh of thin iron rods to reinforce concrete. He took out a patent in 1867 and continued to find new uses for the method which makes the best use of each material.

The technique was soon applied to other structures and in 1875 Monier designed the first iron-reinforced concrete bridge (pont is the French word for bridge).

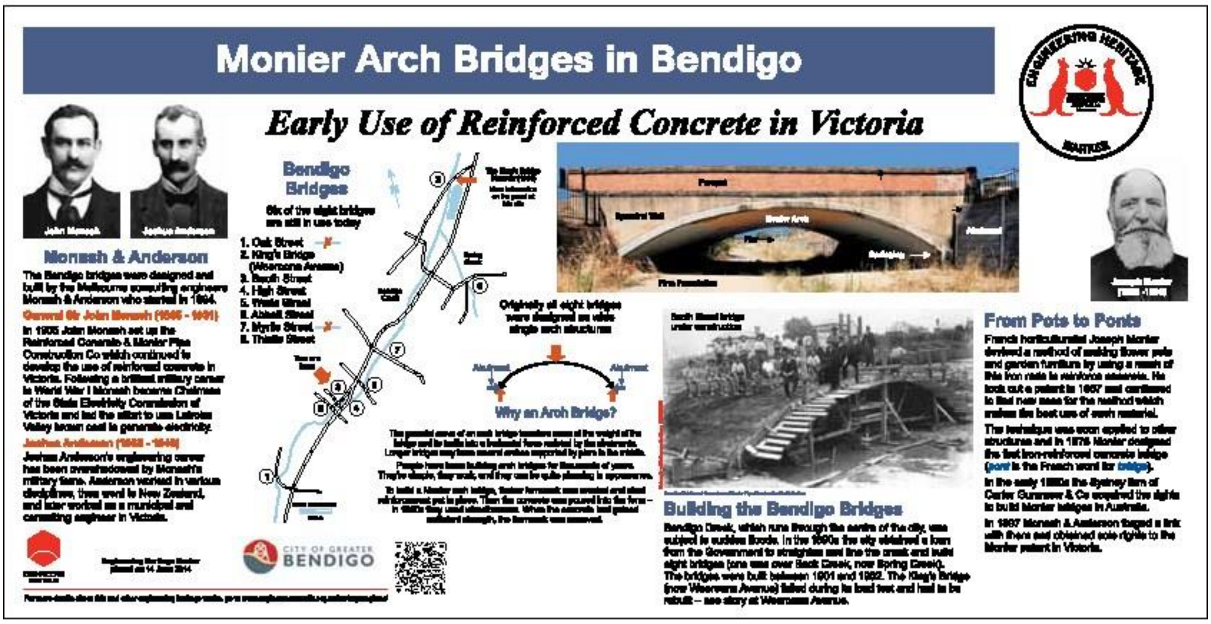
In the early 1890s the Sydney firm of Carter Gummow & Co acquired the rights to build Monier bridges in Australia.

In 1897 Monash & Anderson forged a link with them and obtained sole rights to the Monier patent in Victoria.

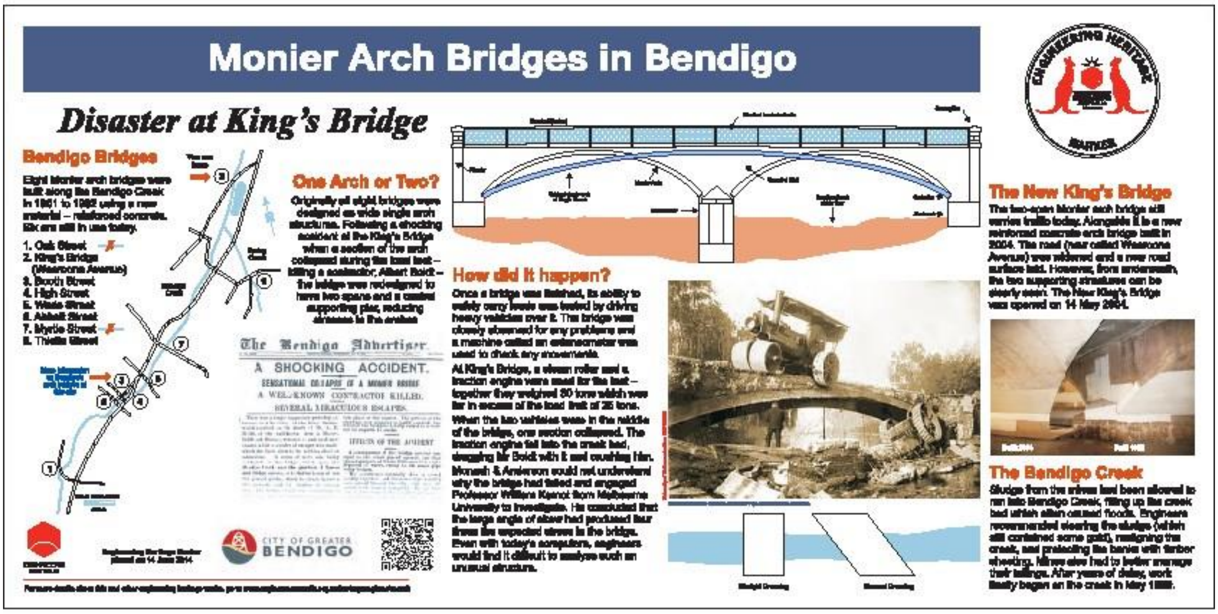
418 words

Drafts of the proposed interpretation panels are shown below. These interpretation panels share some common elements with the 2012/2013 panels erected at Fyansford Bridge in Geelong and Wheelers Bridge near Creswick:

King's Bridge Panel



Old High Street Panel



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Appendix 1: Images with captions

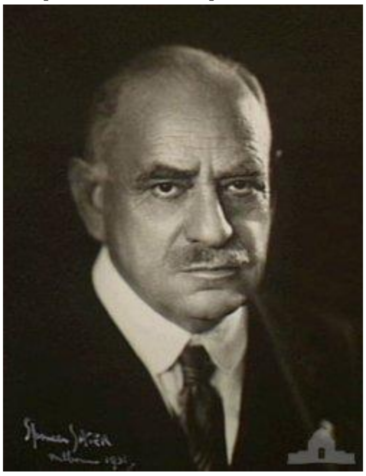
A1.1 Historic Images

The Monash and Anderson Families 1897.

Left to right (back): Joshua Anderson (seated); John Monash (standing); Victoria Monash (seated); Alan Holgate thinks that this is Anderson's brother Jack (standing); Anderson's son, Stewart, born May 1893 (seated); Ellen Anderson (seated); Seated in front left to right: Bertha Monash, born January 1892; The baby must be Alice Anderson, born June 1897; The girl on the right must be Frances Anderson, born November 1894.
Image: National Library of Australia

Appendix 2: Historic Individuals or Associations

A2.1 General Sir John Monash (1865–1931) [6]



Sir John Monash

"John Monash was born in Melbourne on 27 June 1865 into a Prussian-Jewish family. He was educated at Scotch College and Melbourne University. By 1895 he had degrees in arts, engineering and law and had qualified as a municipal surveyor, an engineer of water supply and a patent attorney. As an engineer Monash's early career was in bridge construction working for a time with the Melbourne Harbour Trust, before becoming a partner in a bridge building firm. By the turn of the century his focus had changed to building construction. Monash's military career began in 1884 with his membership of the Melbourne University company of the 4th Battalion, Victoria Militia, and then moving to the North Melbourne Battery of the Metropolitan Brigade of the Militia Garrison Artillery. He was commissioned in 1887. By 1913 Monash had the rank of Colonel and was appointed to command the 13th Infantry Brigade. With the outbreak of World War I in 1914, Monash was transferred from the militia to active service. In 1915 he served as Chief Censor until taking command of the 4th Infantry Brigade (AIF). In this command he served at Gallipoli.

Promoted to Major-General, he commanded the 3rd Division, AIF in France in 1916. Monash succeeded General Birdwood as Australian Corps commander in 1918 and, in the same year, was knighted by King George V in recognition of his role in the Battle of Hamel Hill. With the conclusion of the war, Monash became Director-General of Repatriation and Demobilisation with responsibility for arranging the return of Australian troops from Europe. Back in Australia Monash resumed his engineering career firstly as General Manager and later as Chairman of the State Electricity Commission (SEC) of Victoria. Under his leadership the SEC became an important body in developing Victoria's brown coal reserves as an electricity source and, by 1930, extending the power grid across the whole of the State.

John Monash died in Melbourne on 8 October 1931."

[6] National Archives of Australia, http://www.naa.gov.au/aboutus/publications/factsheets/fs121.aspx, 1997. This document was copied from the Engineering Heritage Victoria Nomination for the Yallourn Power Station by Udara Almeida, 2011.

A2.2 Joshua Thomas Noble Anderson (1865-1949) [7]

"John Monash's subsequent fame overshadowed the contribution made by J. T. N. Anderson to engineering in Victoria and to Monash's early career. The pair formed a business partnership in 1894. In 1897, while Monash was in Western Australia, Anderson forged a link with the Sydney firm of Carter Gummow & Co and obtained through them sole rights to the Monier patent in Victoria. He oversaw the initial negotiations, planning and design for the partnership's first two Monier arch bridges (Fyansford and Wheeler's); obtained many of their commissions and contracts; and consulted widely in the fields of mechanical engineering, water resources and mining.

By 1902 a downturn in the economy and two serious misfortunes had placed the partnership in severe financial trouble and its future was uncertain. Anderson elected to take up a salaried position in charge of design and construction of a new sewerage scheme for Dunedin, New Zealand. It is likely that the pair hoped to form a bridgehead there for the partnership and its related pipe factory, though nothing eventuated. Monash worked in Victoria at trading the firm out of debt and in 1905 it was agreed that the partnership be dissolved. Anderson relinquished his rights and was absolved from his share of the remaining debt. He travelled overseas for some time, then returned to Australia and spent the rest of his life in municipal engineering in Victoria, while retaining his independence as a consulting engineer". [8]

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[7] Alan Holgate Vicnet web site downloaded 10 July 2012.

[8] Anderson's life is summarised in a paper by Brian Lloyd. Stories of the bridge projects in which JTNA was concerned are available on the Alan Holgate web site via the following links: Morell Bridge; Fyansford Bridge; Wheeler's Bridge; Bendigo Arch Bridges; Kings Bridge, Bendigo; Barbers Creek Bridge and Woolert Bridge. There is much more in the archives at UMA and NLA on JTNA's consulting work, e.g. for the Mildura Irrigation Board and the Ballarat Woollen Mills.

A2.3 Joseph Monier (1823 - 1906) [9]

Joseph Monier

“Monier was born in Saint Quentin la Poterie, France and became a renowned French gardener and one of the principal inventors of reinforced concrete.

As a gardener, Monier was not satisfied with the materials available for making flowerpots. Clay was easily broken and wood weathered badly and could be broken by the plant roots. Monier began making cement pots and tubs, but these were not stable enough. In order to strengthen the cement containers, he experimented with embedded iron mesh. He was not the first to experiment with reinforced concrete, but he saw some of the possibilities in the technique, and promoted it extensively.

Monier exhibited his invention at the Paris Exposition of 1867. He obtained his first patent on July 16, 1867, on iron-reinforced troughs for horticulture. He continued to find new uses for the material, and obtained more patents — iron-reinforced cement pipes and basins (1868); iron-reinforced cement panels for building façades (1869); bridges made of iron-reinforced cement (1873); reinforced concrete beams (1878). In 1875 the first iron-reinforced cement bridge ever built was constructed at the Castle of Chazelet. Monier was the designer.

The important point of Monier's idea was that it combined steel and concrete in such a way that the best qualities of each material were brought into play. Concrete is easily procured and shaped. It has considerable compressive or crushing strength, but is somewhat deficient in shearing strength, and distinctly weak in tensile or pulling strength. Steel, on the other hand, is easily procurable in simple forms such as long bars, and is extremely strong. But it is difficult and expensive to work up into customized forms. Concrete had been avoided for making beams, slabs and thin walls because its lack of tensile strength doomed it to fail in such circumstances. But if a concrete slab is reinforced with a network of small steel rods on its under-surface where the tensile stresses occur, its strength will be enormously increased.

Francois Hennebique saw Monier's reinforced concrete tubs and tanks at the Paris Exposition and began experimenting with ways to apply this new material to building construction. He set

[9] Wikipedia, Joseph Monier, downloaded 10 August 2012.

up his own firm the same year and in 1892 he patented a complete building system using the material.

In 1886 German engineer Gustav Adolf Wayss (1851–1917) bought Monier's patent and developed it further. He conducted further research in the use of reinforced concrete as a building material, and established the firm of Wayss & Freytag".

A2.4 Dr Alan Holgate (1937 - Current) [10]

The research of Dr Alan Holgate has been vital to this nomination. His material is collected together in a systematic manner on a Vicnet web site making it very accessible. All students of Monash's work are indebted to Alan for his body of work on Monash.

Alan Holgate was born at Chesterfield, Derbyshire, England in 1937. He now lives at Mooroolbark, in the outer eastern suburbs of Melbourne.

He was educated in various primary schools in Derbyshire and Devon then moved on to Newton Abbot Grammar School, studied civil engineering at University College, London, from 1955 to 1958 and obtained a BSc(Eng).

He carried out supervision of road maintenance and construction with the Department of Main Roads, New South Wales from 1958 to 1961 then worked as Office Engineer at Marples Ridgway & Partners, London from 1961 to 1962.

Returning to Australia he worked on hard rock tunnelling supervision for the Snowy Mountains Hydro-Electric Authority, Eucumbene, Australia from 1962 to 1963 then in power station design, Snowy Mountains Hydro-Electric Authority, Cooma from 1964 to 1965.

He then took up teaching and research in analysis and design of structures with the Department of Civil Engineering, Monash University, Melbourne from 1966 to 1996. During this time he was a lecturer from 1967 to 1971, Senior Lecturer from 1972 to 1993 and Associate Professor from 1994 to 1996.

He obtained his Ph.D. at Monash University in 1996 and since retiring from Monash has been in Independent Scholar.

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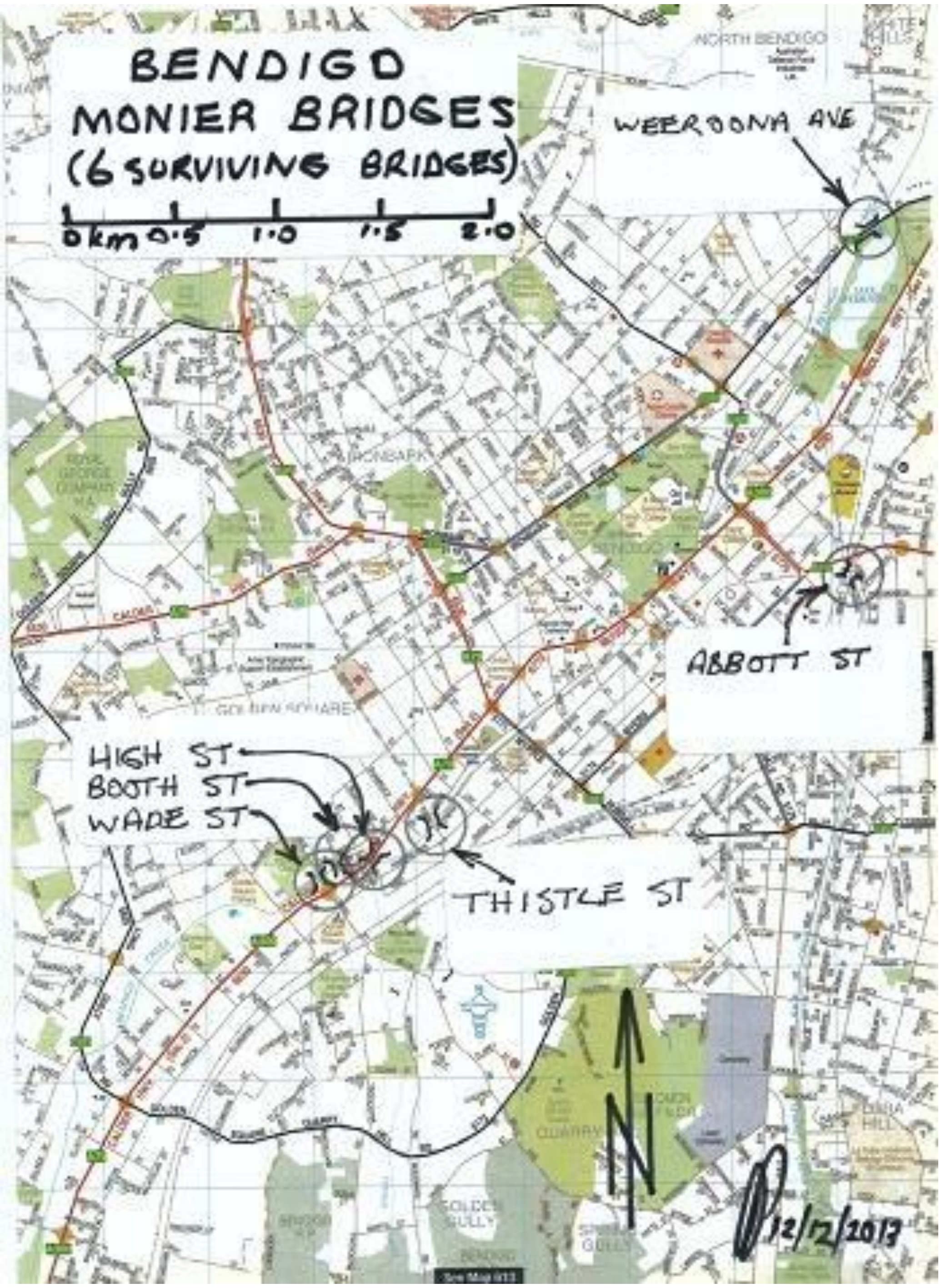
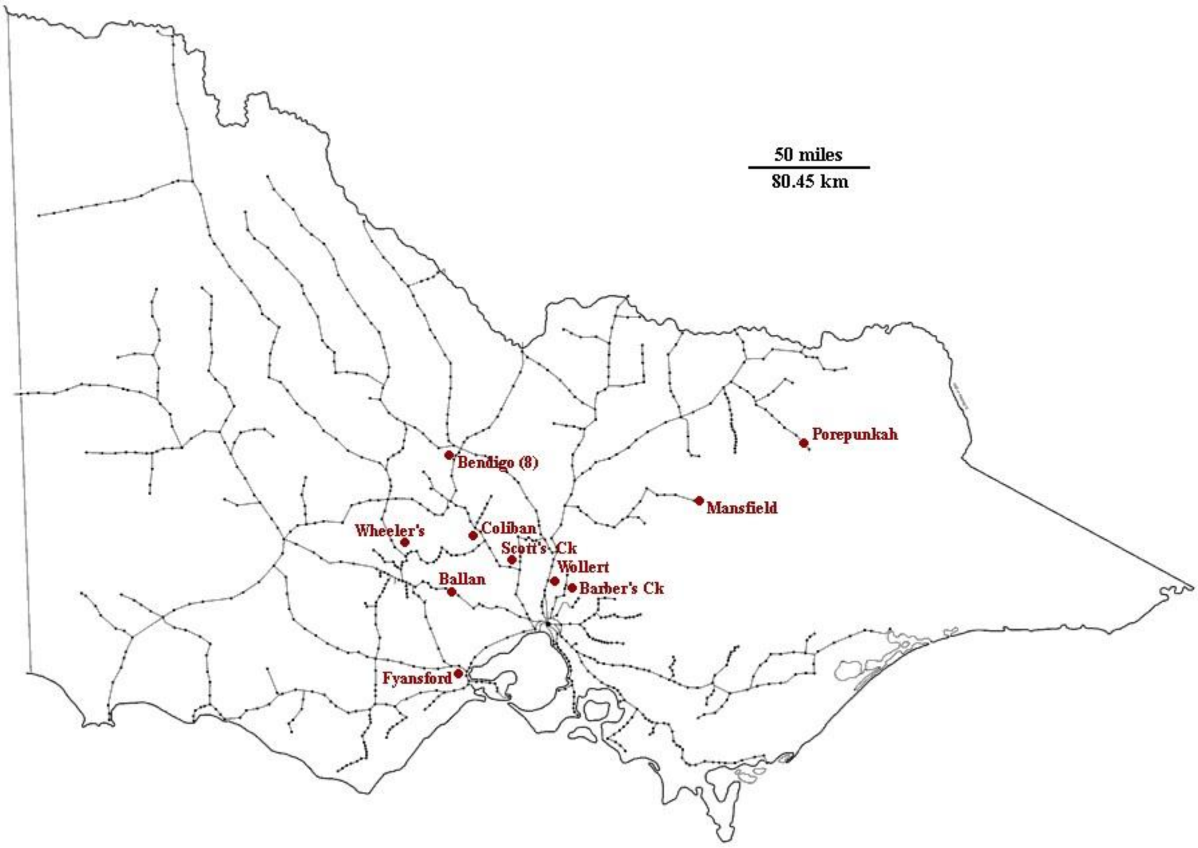
[10] Alan Holgate Vicnet web site downloaded 10 July 2012.

Appendix 3: Maps



A3.1 Location map indicating the six remaining Monier arch style bridges in Bendigo.
Image: Owen Peake



A3.2 Map of Monier Arch Bridges built in Victoria.
Image: Alan Holgate Vicnet website

Appendix 4: List of Monash & Anderson Monier Arch Bridges [11]

Bridge Name	Date	Municipality (present)	Coordinates
Anderson St. "Morell." (attributed to Carter Gummow & Co.)	1899	Melbourne.	-37.8275, 144.9850
Fyansford.	1900	Greater Geelong-Golden Plains.	-38.1420, 144.3087
Wheeler's.	1900	Hepburn.	-37.3230, 143.8916
Oak St.	1901	Greater Bendigo.	
First King's.	1901	Greater Bendigo.	
Booth St.	1901	Greater Bendigo.	-36.769847, 144.261839
High St.	1901	Greater Bendigo.	-36.769628, 144.263867
Wade St.	1901	Greater Bendigo.	-36.77042, 144.26082
Scott's Creek Culvert.	1901	Moorabool.	
Second King's. (Weeroona Ave).	1902	Greater Bendigo.	-36.74364, 144.29165
Abbott St.	1902	Greater Bendigo.	-36.758347, 144.289917

[11] Alan Holgate, list of Arch Bridges.

Myrtle St.	1902	Greater Bendigo.	
Thistle St.	1902	Greater Bendigo.	-36.76837, 144.26710
Barber's Creek.	1901	Whittlesea.	-37.57440, 145.10448
Wollert.	1901	Whittlesea.	-37.59590, 145.05357
Coliban.	1902	Macedon Ranges.	-37.284840, 144.397248
Ford's Creek.	1903	Delatite.	
Ballan.	1905	Moorabool.	
Porepunkah.[12]	1913	Alpine.	-36.69700, 146.89393

[12] This bridge was constructed well after the Monash & Anderson partnership was dissolved in 1905.

Appendix 5: Time Line for John Monash [13]

1865	Birth - 27 June, at Dudley Street, West Melbourne
1874-75	Resided with family in Jerilderie, New South Wales
1877-81	Student at Scotch College
1882	Enrolled at University of Melbourne
1884	Joined University Company of the Victorian Rifles, appointed Colour-Sergeant in 1886
1884-87	Employed on construction of Princes Bridge and other bridge works in Melbourne for David Munro & Co.
1887	Commissioned in the Militia Garrison Artillery
1887	Took charge of construction works for Outer Circle Railway, Melbourne
1891	Married Victoria Moss
1893	Master of Civil Engineering
	Birth of daughter Bertha
1892-94	Assistant Engineer and Chief Draftsman of Melbourne Harbour Trust. Qualified as Municipal Surveyor, Engineer for Water Supply and as Patent Agent
1894-1905	Private Practice (Monash and Anderson) as Consulting Engineer and Patent Attorney
1895	Awarded Bachelor of Arts and Bachelor of Laws
1897-99	Legal and engineering work in Queensland, New South Wales and Western Australia
1901	Formed Monier Pipe Company Pty. Ltd. (Monash, Anderson and Mitchell) in Melbourne
1905	Formed Reinforced Concrete and Monier Pipe Construction Company Pty. Ltd. (Monash and Mitchell) in Melbourne
1907	Took command of Victorian Section of newly formed Army Intelligence Corps
1908	Promoted to Lieutenant-Colonel
1912	President of Victorian Institution [14] of Engineers
1913	Appointed Colonel and commander of 13th Infantry Brigade in Victoria

[13] Monash University web site downloaded 10 July 2012.

[14] Institute corrected to Institution for clarity. This organisation pre-dated the Institution of Engineers Australia which was formed in 1919.

1914	Leaves Australia in command of 4th Infantry Brigade, Australian Imperial Force (AIF)
1915	Promoted to Brigadier-General
1916	Promoted Major-General in command of new 3rd Division
1918	Knighted by King George V in the field
1918	Appointed Australian Corps Commander and promoted to Lieutenant-General
1919	Returned to Australia
1920	Death of Victoria Monash
	Appointed General Manager of the State Electricity Commission of Victoria (SECV).
1921	Awarded Doctor of Engineering
	Appointed Chairman of the State Electricity Commission of Victoria
1921-31	Oversees design and construction of Shrine of Remembrance, Melbourne
1923	Chairman of Royal Commission into police strike
1923-31	Vice-Chancellor of the University of Melbourne
1929	Promoted to General
	Awarded Peter Nicol Russell Memorial Medal [15] (Institution [16] of Engineers, Australia)
1930	Awarded Kernot Memorial Medal (University of Melbourne) for brown coal development
1931	Death - 8 October

[15] Often referred to as the Peter Nicol Russell Medal.

[16] Institute corrected to Institution for clarity.

Appendix 6: Time Line for Bendigo Monier Arch Bridges [17]

1890s	The City of Bendigo obtains a loan from the government to assist with work on Bendigo Creek which is subject to sudden floods and carries large amounts of sludge from nearby mines. The process is to involve straightening and lining the creek and reconstruction of eight bridges (seven on Bendigo Creek, one on Back Creek).
Aug. 1899	J. Monash & J. N. T. Anderson propose a Monier style arch bridge for the High Street Bridge, consisting of a 55ft span and 99ft width, a new concrete and supposedly cheaper design. J. R. Richardson, the City Surveyor, proposes a more traditional iron girder on brick pillar construction. After the successful proposal, Monash & Anderson prepare designs of the other proposed bridges.
Oct. 1899	Richardson demands further specifications to be made to the designs, causing Monash & Anderson to make amendments.
July 1900	After the original tenders, of which prices exceeded the loan, the Council calls for fresh tenders for the eight bridges following discussions and proposals of several designs. Monash & Anderson submit plans and specifications for the bridges, including considerations for Richardson's modifications.
Aug. 1900	Prior to the submission for tenders, Monash & Anderson meet in Bendigo for a public exhibition of drawings and specifications.
Oct. 1900	Council decide to award the contract of all eight bridges to Monash & Anderson with a total price of £6,967 (5th). Monash travels to Bendigo to meet the Mayor and sign contracts (23rd and 24th, respectively). Richardson demands extra provisions, including twice the load (totalling 30 tons) for testing to accommodate the transit of large mining machinery. Assistant engineer J. S. Gregory produces simple drawings of the bridges. Work begins on dismantling the existing bridge and excavations at Oak Street Bridge (26th) under the command of foreman J. Buick.
Nov. 1900	Abutments are cast and ready for centre framework to support the arch at Oak Street Bridge (10th). The first of several floods occurrs (18th) and Monash supervises the casting of the first Monier arch in Bendigo (23rd). Monash & Anderson alter the road alignment, thus reducing the cost and skew of the King's Street Bridge and improving stability and strength. The removal of the existing bridge and excavations at King's Street Bridge commence, of which there is poor excavation material.
Jan. 1901	The first horse-and-trap passes over the first completed Monier arch bridge in Bendigo at Oak Street Bridge (8th). Monash & Anderson make a slight modification to the King's Street Bridge, reducing the cross-section.

[17] Events extracted from John Monash, Engineering enterprise prior to WWI, The Bendigo Monier Arch Bridges. Contract acquisition, planning, design and construction.
http://www.aholgate.com/texts/bgobrshist.html

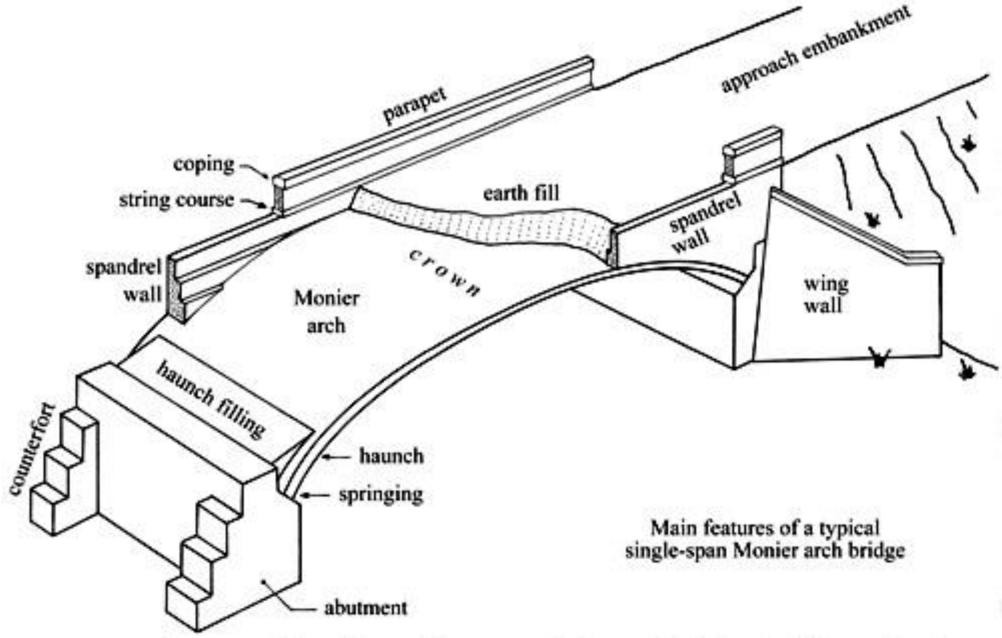
Feb. 1901	The Oak Street Bridge is tested and approved (5th). Monash & Anderson are present for the first turning of the strip at King's Street Bridge (8th). Work on the High Street Bridge is commenced (12th). The centre framework is required to be cut to be removed due to the arch sagging, thus delaying reuse of the centres and delaying construction (27th).
March 1901	An argument occurs between Buick and the senior foreman, C. Christensen, results in Buick's resignation (31st). Monash travels to Bendigo to sort out the problem and finds a new foreman as a replacement to assist Christensen.
April 1901	King's Street Bridge has the third strip cast (1st), work commences on Booth Street Bridge (17th) and the first strip is cast at High Street Bridge (18th).
May 1901	Gregory surveys the High Street Bridge profile, prepares drawings and checks calculations (3rd). King's Street Bridge is tested with the large 30 ton load as specified by Richardson and results in a collapse, causing a single fatality (14th). Monash & Anderson state they will rebuild the bridge at their own expense. Investigations into the King's Street Bridge collapse are undertaken with assistance from Professor W. C. Kernot at the University of Melbourne. Gregory double checks the strength of the King's Street Bridge (22nd) and the High Street Bridge (28th). Kernot determines the failure is due to an underestimation of the maximum stresses by about a factor of four, resulting from the conventional established theory being unsuitable for highly skewed arches. A coroner states the death was accidental (30th).
June 1901	A flood destroys the centres for the Booth Street Bridge (17th), but they are successfully constructed and turned later (22nd). Two strips of the High Street Bridge are completed.
July 1901	The King's Street Bridge is redesigned, consisting of two arches of half the original span each and resting on a central pier. The failed bridge is cleared.
Aug. 1901	Remaining strips of High Street Bridge are completed (18th, 19th) and Booth Street Bridge is successfully tested.
Sept. 1901	The Wade Street Bridge arch is turned (17th) but later destroyed by a flood (18th). The downstream abutments are out of line and need correction at High Street Bridge (18th). Excavation and alignment work has begun at Abbott Street Bridge and involves discrepancies regarding earthworks.
Oct. 1901	Monash & Anderson are present for the successful load test of the High Street Bridge (3rd). The Wade Street Bridge arch is constructed and turned successfully (7th).
Nov. 1901	Arch turned on the new King's Street Bridge (20th).
Dec. 1901	The Wade Street Bridge is successfully tested (2nd).
Jan. 1902	A test of the new King's Street Bridge is successfully carried out with a 15 ton load, costing Monash & Anderson £1,000 in construction (28th). The Myrtle Street Bridge is successfully turned (29th). The Abbott St Bridge is successfully completed in early 1902, between the completions of the second King's Street Bridge and Myrtle Street Bridges.

March 1902 The Myrtle Street Bridge is successfully tested (3rd) and the Thistle Street arch is turned (8th).

May 1902 The last Bendigo Monier arch bridge, Thistle Street Bridge is successfully tested (12th). Monash follows up a claim on the extra costs incurred as a result of the extensive abutments required at High Street, to which the Council makes a compromise.

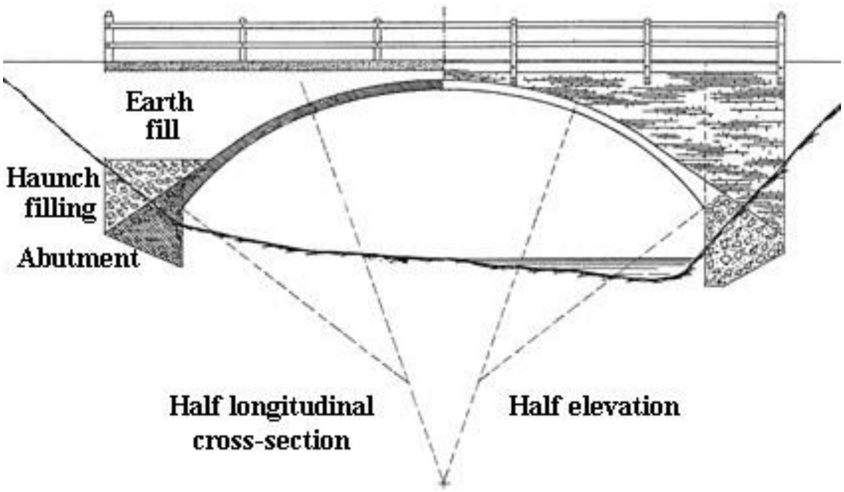
Appendix 7: Basic calculations for Monier arch bridges as carried out by Monash & Anderson. [18]

This web page is devoted to the procedures used by Monash and Anderson, and their engineering assistants, to determine the profile for a Monier arch, and to calculate the resulting forces and stresses. It assumes that the reader has some basic knowledge of the mechanics of structures. It is restricted to the techniques used for M&A's early bridges, which were checked only for symmetrical uniformly distributed live load. The Upper Coliban Spillway Bridge is used as an example. Computations were sent to Sydney to be checked by W. J. Baltzer and F. M. Gummow. Baltzer had earlier used more complex procedures for the design and analysis of the Anderson Street (Morell) Bridge. After the collapse of the first King's Bridge at Bendigo, Monash obtained from him details of procedures for analysis for non-symmetrical and point loads, the most important 'point' loads being the axles of the steam rollers used in testing the bridges.



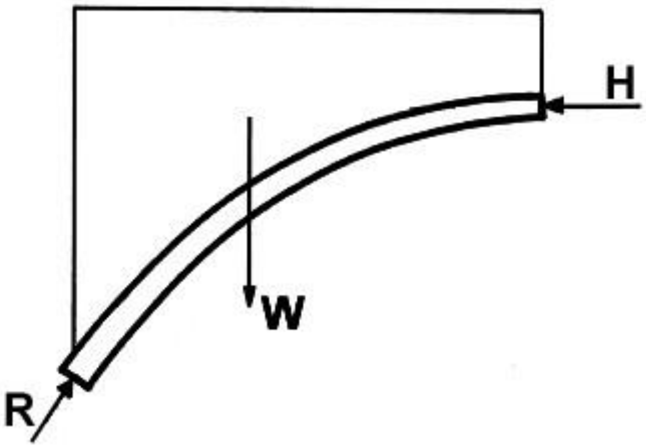
The process used for design was a sort of 'form-finding'. At this early stage in the development of reinforced concrete, M&A and their advisors were unaware of any method for taking into account the presence of the reinforcement in an arch cross-section subjected to combined axial load and bending moment. The grids of small diameter bars provided in the Monier system were therefore ignored in analysis, and the aim was to shape the curve of the arch to avoid tensile stresses under normal loading conditions. This was achieved by ensuring that the centreline of the profile coincided with the line of thrust due to the self-weight of the arch, spandrel walls and filling. (Sometimes live load was included at this stage.) Checks were then made on varying live load conditions applied to the chosen form, to ensure that the thrust line did not deviate greatly from the centreline. Because the self-weight of the bridge was enormous in comparison with the live load, this was rarely a problem in theory. (In practice it turned out that the arch curve as built often deviated considerably from the theoretical curve owing to deflection and subsidence of falsework, and this was a much more significant cause of bending stress.)

[18] Alan Holgate Vicnet web site downloaded 10 July 2012.

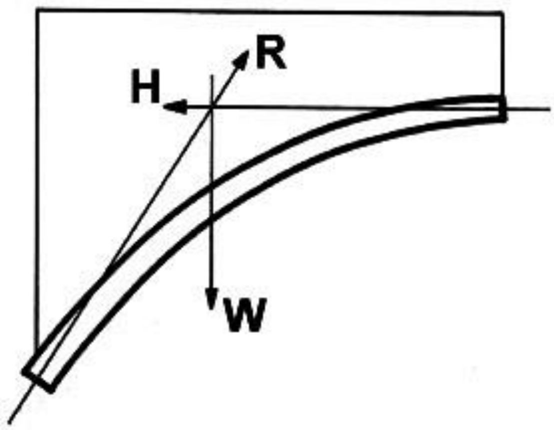


The left-hand side of the above drawing shows half of the longitudinal cross-section of a typical Monier arch bridge. The right hand side shows half of the side elevation. The arch profile is made up of three circular segments, as indicated by the radii. This is a simplified version of part of the working drawing for Ford's Ck Bridge, Mansfield. For a more complete extract click here.

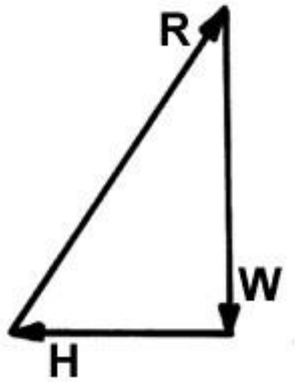
The process of form-finding was iterative. All bridges were assumed symmetrical about the vertical centreline of the elevation, so that one half of the span could be treated as a 'free body' subjected to three forces: W, the total weight; R, the inclined reaction from the abutment; and H, the thrust in the crown exerted by the other half of the bridge.



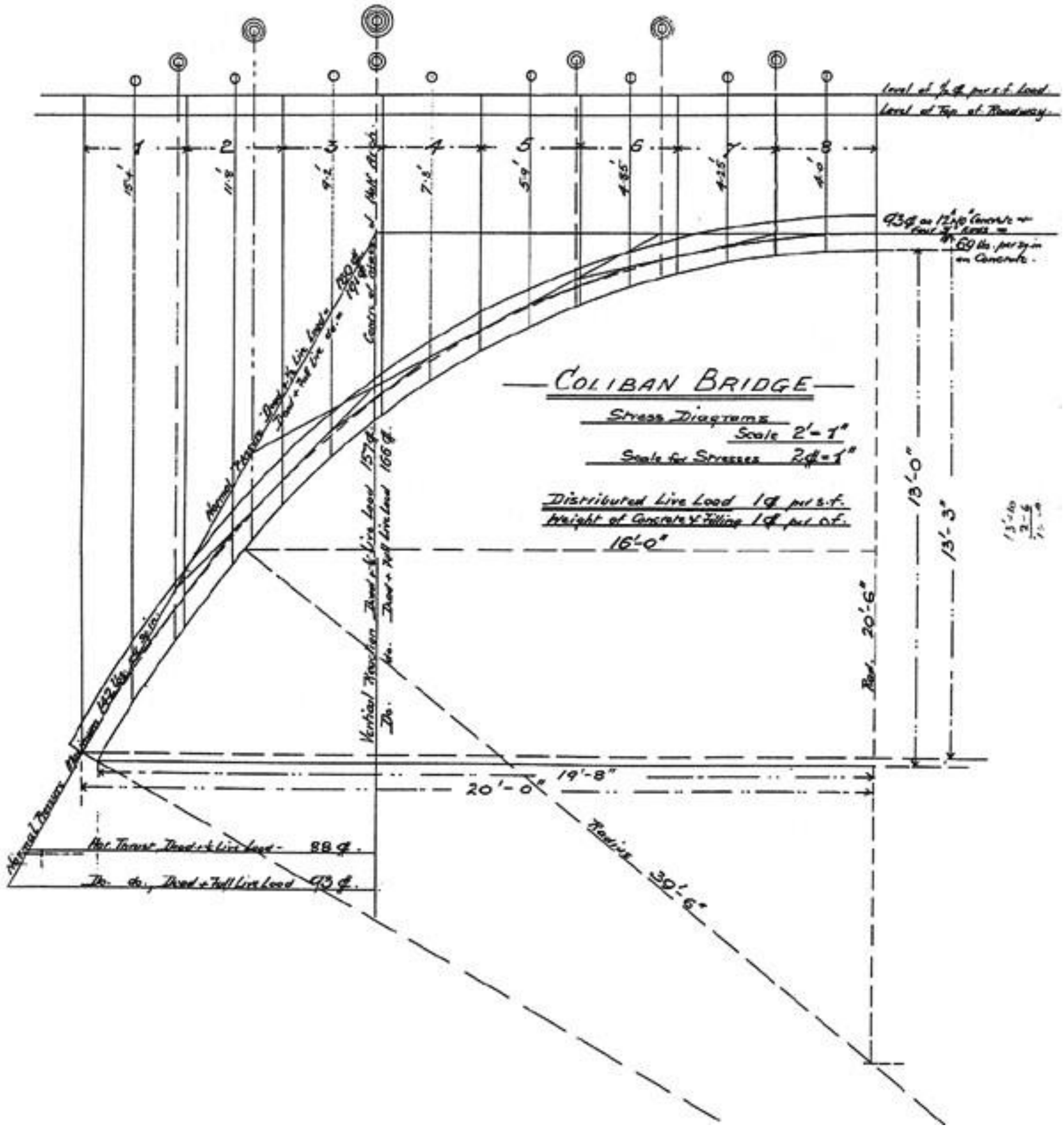
Because of the symmetry, and in the absence of a point load at the crown, H was horizontal. Assuming that the desired form had already been found, both H and R would pass through the centreline of the arch thickness, while W passed through the centroid of the half-arch. The lines of action of three forces which are in equilibrium intersect. Thus R passed through the intersection point of W and H.



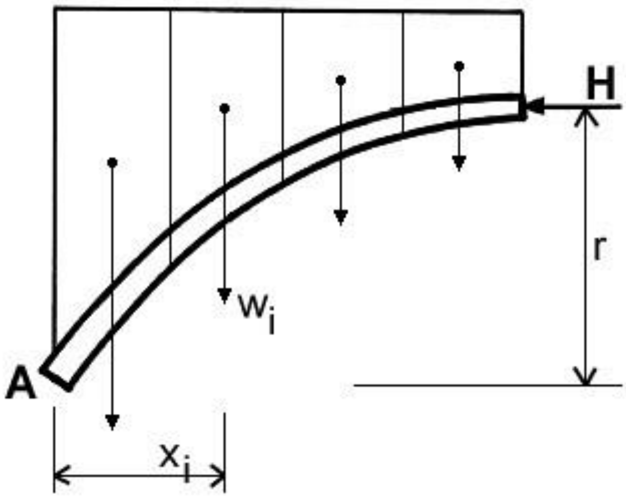
Hence a triangle of forces could be drawn. This gave the direction of R, while the magnitude of R and H could be determined by scaling from the known value of W. (H could also be obtained by taking moments about the abutment.)



This approach is evident in the drawing which J. S. Gregory produced for the Upper Coliban Spillway Bridge. (see below)



In the actual calculation process, the spandrels and fill above the half-arch were conceived as broken into segments by taking vertical slices across the width of the bridge. For clarity, only four are shown in the figure below, but normally eight were taken. It was customary to work with a strip of arch adjacent to the edge and one foot wide. The weight of the live load, when included, was indicated on the drawings as a surcharge comprised of an equally heavy volume of fill. In the Coliban calculations it appears that when the weight of a segment was calculated the specific weights of reinforced concrete, mass concrete, and earth fill were simply taken as a uniform 1 cwt force (112 lbf) per cubic foot (17.6 kN/m^3). When the arch was considered by itself (supporting its own weight during construction, or for an alternative scheme with timber superstructure) the specific weight of 'Monier' was taken as 150 lbf per cubic foot.



Taking moments about the springing point A:

H r = Sum (w_i x_i) thus

H = (Sum w_i x_i) / r

This approach is evident in the tabular calculations represented below. The same tables permitted the calculation of the total mass above the half-arch (Sum w_i) and the position of its centroid so that the location of the force W could be established.

In the table reproduced below, the effective half-span is taken as 20.08 feet and is split into eight vertical segments each of width K = 20.08 / 8 = 2.51 feet. The centre of gravity of each segment lies at the centroid of its area as seen in elevation. This is assumed to be midway between its vertical edges. The distances from the springing point to each centroid are expressed throughout in terms of K. For a one-foot wide slice in the direction of the span, the volume of each segment is one foot multiplied by its area as seen in elevation, i.e. 1 × K × (average depth). The average depths have been scaled from the drawing as 15.4, 11.8, etc. As the unit weight of all materials is taken as 1 cwt per cubic foot, the weight of a segment is simply 1 × K × (av. depth) × 1 = K × (av. depth). In column 2 the weight W of the one-foot wide slice of the half-span is summed as 62.62 K = 157.17 cwt. Its first moment about the abutment (Column 3) is 184.29 K^2 = 1161 foot-cwt. Hence the centroid lies 1161/157 or about 7.38 feet from the abutment. With these facts it is now possible to obtain the magnitudes of H and R and the direction of R.

Final set of calculations for Coliban Spillway Bridge "accepted design" with masonry spandrels.

by J. S. Gregory, 21 August 1901 (edited for this website.)
Dead load plus half live load. Span = 39'-4", Rise = 13'.
K = 20.08 / 8 = 2.51

Column 1	Column 2		Column 3		Column 4	Column 5
Lever arm from springing.	Weight of segment.		Moment of weight about springing.		Segments grouped in twos.	Segments grouped in fours.
K × 1/2 K × 3/2	15.40 K 11.80 K	27.20	7.70 K^2 17.70 K^2	25.40	25.40 K^2 / 27.20 K= 2.34	73.95 K^2 / 43.70 K = 4.24
K × 5/2 K × 7/2	9.20 K 7.30 K	16.50	23.00 K^2 25.55 K^2	48.55	48.55 K^2 / 16.50 K = 7.38	
K × 9/2 K × 11/2	5.86 K 4.86 K	10.72	26.37 K^2 26.73 K^2	53.10	53.10 K^2 / 10.72 K = 12.43	110.34 K^2 / 18.92 K = 14.63
K × 13/2 K × 15/2	4.25 K 3.95 K	8.20	27.62 K^2 29.62 K^2	57.24	57.24 K^2 / 8.20 K = 17.52	
	62.62 K		184.29 K^2			

Distance of centre of gravity of whole from abutment point = 184.29 K^2 / 62.62 K = 7.38'
Horizontal thrust = 184.29 × 6.3 / 13.25 = 87.6 cwt. Vertical Reaction = 157.17 cwt.

In the calculation for horizontal thrust 184.29 × 6.3 / 13.25, the 6.3 is K^2 and the 13.25 is 13'3", the rise from the abutment "hinge" to the centreline of the arch at the crown i.e. to the level of the horizontal thrust in the crown. The vertical reaction at the abutment must equal the total weight of the segments, 157.17.

To trace the full pressure curve within the arch the vertical slices are grouped first into four groups of two (Column 4). The positions of the centres of gravity are determined for each

group. In Column 5 two groups of four segments are taken. This process can be traced through the system of symbols at the top of the drawing, consisting of small concentric circles:

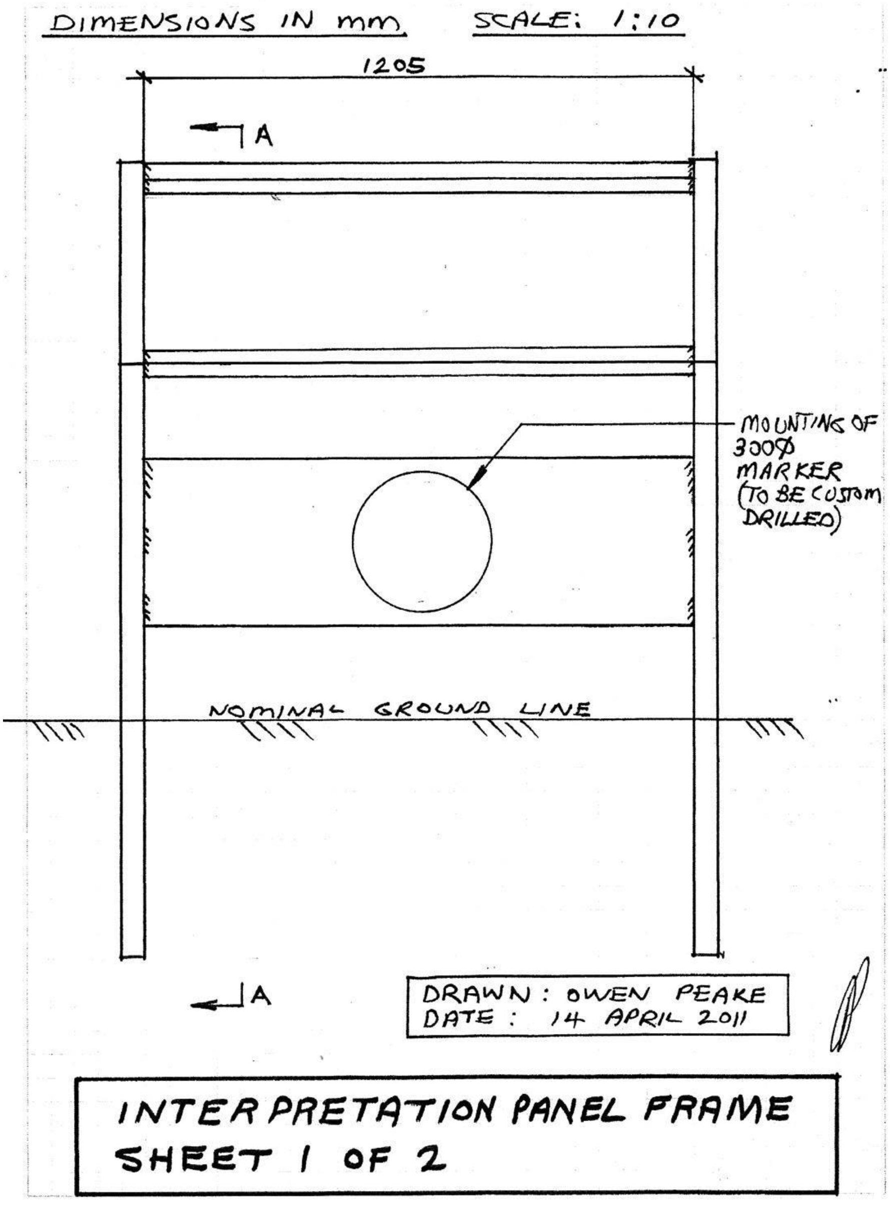
Four small circles indicate the position of the total load W. Part way down its line of action, the intersecting lines of H and R can be seen.

Three small circles indicate the weight of the two groups of four segments. The points where their lines of action cut H and R are joined by a construction line.

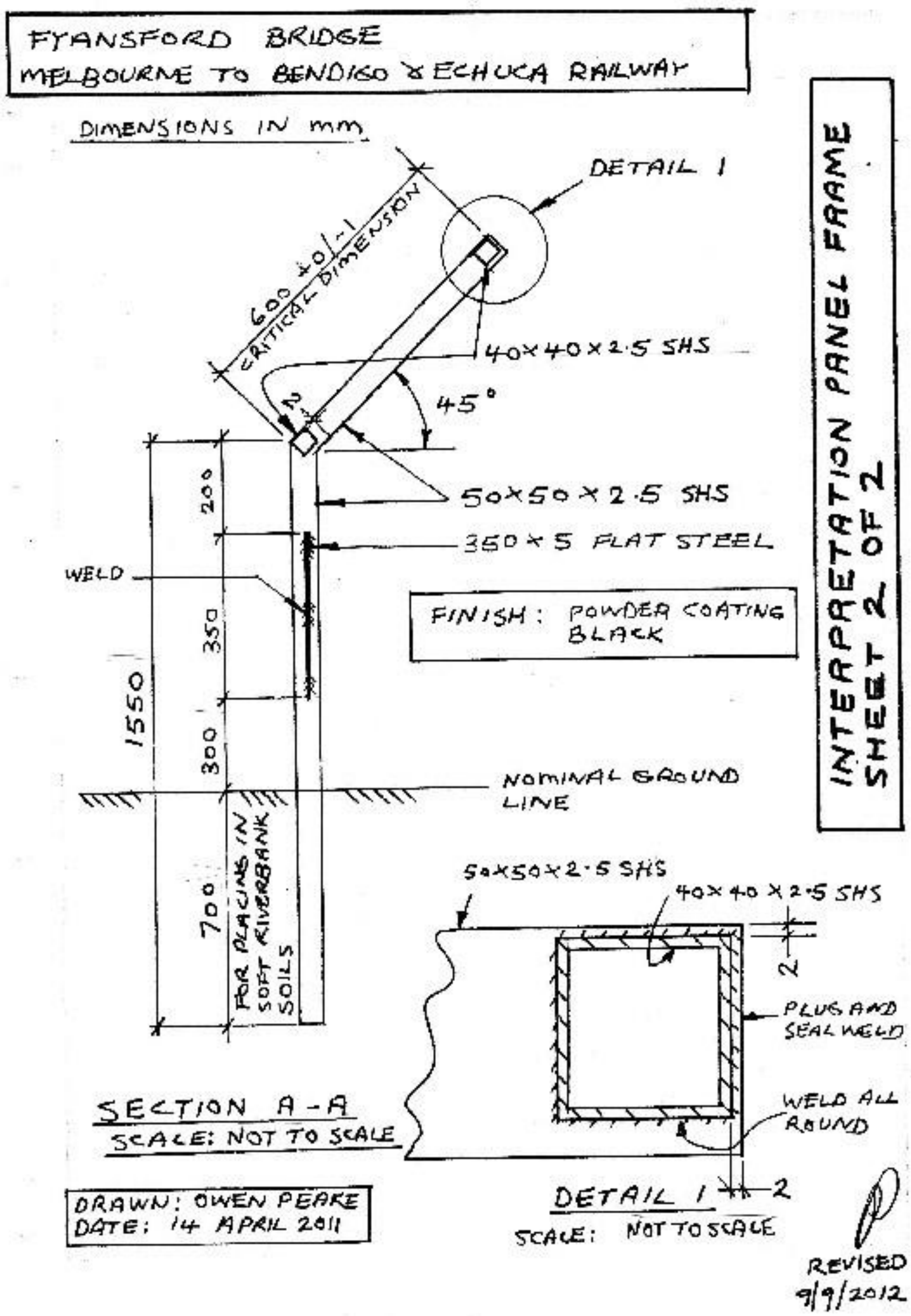
This process is repeated until the level of the individual segment is reached, resulting in the thrust line, shown dashed.

If the thrust curve differed significantly from the initially-assumed profile of the arch, the arch shape would be adjusted to fit the pressure curve, and the calculations repeated using revised segment weights. Generally, only two iterations were needed to achieve satisfactory agreement.

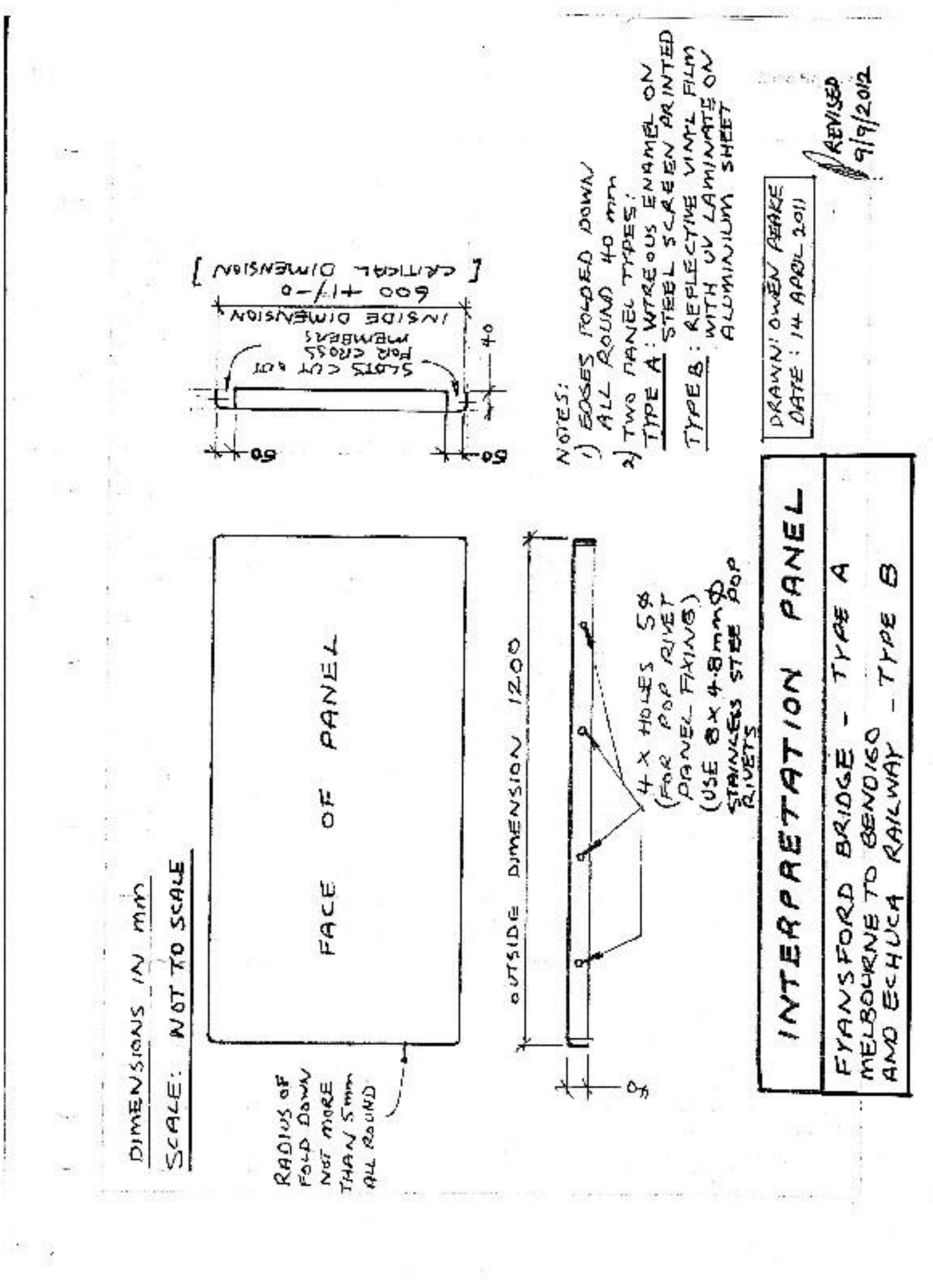
Appendix 8: Interpretation Panel & Mounting Frame Drawings



Drawing 1 – Interpretation Panel Mounting Frame Sheet 1 of 2
Image: Owen Peake



Drawing 2 – Interpretation Panel Mounting Frame Sheet 2 of 2
Image: Owen Peake



Drawing 3 – Interpretation Panel [19]
Image: Owen Peake

[19] Note that this panel is a Type A (vitreous enamel) in note 2 above.

Appendix 9: Letter of Approval from Owners

INSERT LETTER OF APPROVAL

CHANGE CONTROL

VERSION 1	**21/01/2014**	**9,910 WORDS**	**COMMENCED DRAFTING; NOMINATION AS STARTING POINT. BASIC REPORT FORMATTING AND TITLES, CONSOLIDATION OF RESEARCH AND IMAGES, BEGIN APPENDICES AND REFERENCES.**
VERSION 2	**23/01/2014**	**9,660 WORDS**	**EDITTED DRAFT, FORMATING, PROOFREAD, MINOR DETAILS, NOTES OF FURTHER AMENDMENTS NEEDED**
VERSION 3	**29/01/2014**	**12,529 WORDS**	**IMAGE CAPTIONS, UNIFORMITY, SPELLING, ATTRIBUTIONS, ADDITIONAL FOOTNOTES, REVISED APPENDICES (IMAGES, MAPS, TIMELINES)**
VERSION 4	**02/02/2014**	**12,944 WORDS**	**TRACK CHANGE COMMENTS ADDED BY OP**
VERSION 5	**04/02/2014**	**13,683 WORDS**	**NOMINATION LETTER, SPELLING, COMMENTS BY OP ADDRESSED, UNIFORMITY, ATTRIBUTIONS, ADDITIONAL FOOTNOTES, REVISED STATEMENT OF SIGNIFICANCE**
VERSION 6	**05/02/2014**	**13,759 WORDS**	**COMMENTS BY OP FURTHER ADDRESSED, REVISED TIMELINE (APPENDIX), FORMATTING, REFERENCES REVISED, SECTION WORD COUNTS REVISED AND CORRECTED WHERE APPLICABLE**
VERSION 7	**08/02/2014**	**13,781 WORDS**	**MINOR FORMATTING BY OP**
VERSION 8	**19/02/2014**	**14,479 WORDS**	**TABLE OF CONTENTS, MINOR EDITTING**
VERSION 9	**3/03/2014**	**14,779 WORDS**	**FINAL DRAFT AS RECEIVED FROM STEVE & JUSTIN**
VERSION 10	**1/5/2014**	**14,875 WORDS**	**INCORPORATED CORRECTIONS FROM DAVID BEAUCHAMP**
VERSION 11	**2/5/2014**	**14,935 WORDS**	**EDITING**
VERSION 12	**3/5/2014**	**14,820 WORDS**	**TEST CONVERSION TO PDF & BACK TO REDUCE FILE SIZE**
VERSION 13	**12/5/2014**	**15016 WORDS**	**EDITING**
VERSION 14	**25/5/2014**	**15021 WORDS**	**PROOF READING INCORPORATED**